LOS ANGELES TO SAN DIEGO
THREE DIMENSIONAL
OZONE TRANSPORT STUDY

FINAL REPORT

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PREFACE

This report was submitted in fulfillment of contract No. ARB A6-090-30 with the California Air Resources Board by Metro Monitoring Services. The report includes the analysis of meteorological and ozone data measured by Metro Monitoring Services and data from cooperating agencies, furnished by the California Air Resources Board through December 17, 1976. The field measurement and data analysis program conducted by Metro Monitoring Services was part of a cooperative project involving the California Air Resources Board, San Diego County Air Pollution Control District, and the Naval Postgraduate School at Monterey in conjunction with the Naval Air Systems command and the Naval Research Laboratory. At the time of data analysis and report preparation to meet the contract deadline, some of the meteorological and air quality from the participants was not available. Specifically, the following data were not available:

1. the Arcania ship positions and ozone data;
2. the Navy ship surface weather observations;
3. the Navy Pt. Mugu weather observations (primarily upper air);
4. the CARB ozone data at Catalina (Isthmus), San Clemente, and San Nicolas Islands; and
5. ozone data from the single engine Bellanca aircraft operated by Airborne Research Associates, (Dr. Ralph Markson).

It is envisioned that analysis of these additional data will serve to refine the results and enhance the conclusions.

ABSTRACT

The three dimensional distributions of ozone concentrations and meteorological parameters were measured during a ten-day period which included an entire Santa Ana (Northeasterly) wind episode in the South Coast Air Basin. The ozone concentrations and wind and temperature structure were measured by an instrumented light aircraft and network of wind and ozone monitors in the coastal area between Los Angeles and San Diego, including the off-shore islands.

Air masses with high ozone concentrations in the lower 200 feet were commonly found over the ocean south of Los Angeles during Santa Ana wind conditions; during "marine layer" conditions, the high ozone concentrations were observed at or above the base of the characteristic subsidence inversion existing between Los Angeles and San Diego.

Concurrent surface and upper air wind measurements made at intervals throughout the days and nights provide data from which streamline airflow maps were prepared for the levels associated with high ozone concentrations. Airmass trajectories constructed from these streamline maps indicate that the measured high ozone concentrations at the surface and aloft over coastal San Diego most likely originated from precursor emissions in the Los Angeles - Orange County area. The relationship between ozone aloft, precursor origin and measured ozone at the surface in eastern San Diego County is less well established.

TABLE OF CONTENTS

VOLUME I

		Page
PREFACE		
ABSTRACT		
I	SUMMARY	1
II	INTRODUCTION	3
III	EQUIPMENT AND PROCEDURES	6
IV	INSTRUMENT CALIBRATION, COMPARISONS AND DATA REDUCTION	12
V	METEOROLOGICAL SETTING	14
VI	OZONE TRANSPORT RESULTS	17
	A. THE SANTA ANA CASE	17
	B. THE MARINE LAYER CASE	22
VII	OTHER ANALYSES	25
	A. ESTIMATION OF BACKGROUND OZONE LEVELS	25
	B. PRIMARY POLLUTANT - OZONE RELATIONSHIPS	25
	C. COMPARISON OF TRAJECTORIES DERIVED FROM SURFACE AND UPPER AIR DATA	27
	D. TIME CROSS-SECTIONS ALONG A TRAJECTORY	28
	E. SOUTHERN CALIFORNIA-WIDE OCCURRENCE OF OZONE	31
	F. RELATIONSHIP BETWEEN OZONE ALOFT AND SURFACE OZONE	33
VIII	CONCLUSIONS AND RECOMMENDATIONS	35
IX	ACKNOWLEDGEMENTS	38
X	REFERENCES	39
	APPENDIX A SELECTED PHOTOGRAPHS	

TABLE OF CONTENTS, (Continued)

VOLUME II (DATA SUPPLEMENT)

APPENDIX B,	Surface and Upper Air Weather Maps, U. S. Dept. of Commerce, NOAA
APPENDIX C	Winds Aloft Data, M_2S Measurements
APPENDIX D	Ozone Data, Black Jack Camp, Santa Catalina Island
APPENDIX E	Aircraft-derived Pollutant Data Airborne Sensor Data Bag Sample Data
APPENDIX F	Aircraft Flight Paths and Data Display
APPENDIX G	Temperature and Ozone Soundings
APPENDIX H	Cross-sections
APPENDIX I	Trajectory Maps
APPENDIX J	Streamline and Horizontal Ozone Distribution Maps
APPENDIX K	Southern California Maximum Hourly Ozone Maps

I SUMMARY

An intensive three-dimensional meteorological and pollutant measuring program was undertaken over a ten day period, October 5-14, 1976. The focus of the work was along the coast between Long Beach, in the South Coastal Air Basin (SCAB) and San Diego.

The field program was planned to coincide with the appearance of "Santa Ana" wind flow conditions, which have been previously noted as being the causation of high ozone values occasionally reported by the San Diego Air Pollution Control District (SDAPCD).

This California Air Resources Board (ARB) project was also designed to produce data concurrently with a U. S. Navy fog study operation which included an instrumented ship and aircraft, taking measurements off-shore.

The appearance and decay of a "Santa Ana" condition was successfully studied, but much of the Navy data, as of this writing, is not yet available for conclusion in the analysis of this study.

The "Santa Ana" condition resulted in a maximum one-hour average ozone concentration of 0.29 ppm, the highest value reported by the SD APCD for the past five years.

Use of winds aloft data, obtained by a special network of 4 pilot balloon stations, plus that from the National Weather Service stations between Los Angeles and San Diego, and reports from the Navy at San Clemente Island and Point Loma, made it possible to construct the trajectory or path taken by a given air parcel as it moved across the area under the influence of the varying wind field.

All parcels which were found to have an associated maximum ozone value were traced backward in time, to

establish the origin of the ozone. In the "Santa Ana" cases studied, there was no question that the source of the air containing high ozone values in San Diego county was the SCAB.

Preceeding and following the "Santa Ana" were periods of more normal summer conditions, a moderately deep marine layer, capped by an inversion near 1000-2000 feet (300-600 m). Ozone maxima associated with these conditions were lower in concentration than those for the "Santa Ana" flow.

A characteristic of the ozone pattern found with the marine layer conditions was the presence of a layer of maximum ozone just above the base of the inversion, in the stable air above the mixed layer.

Trajectories developed for these situations also indicate that San Diego experiences elevated ozone readings due to transport from the SCAB under these more normal conditions.

In many of the days studied the ozone aloft, as detected by the aircraft, was about equal to the maximum obtained by the ground stations in the SD APCD network. The explanation for this situation is not readily apparent. The fumigation of the ozone from aloft would be expected to result in a lower concentration at the surface, due to the mixing with air containing lower ozone concentrations. Another possibility exists, namely, that the whole mixed layer contains a constant amount of primary pollutants. However, only that at the top has access to the sun's ultra violet radiation during the early morning hours, thus limiting the ozone to that level. When the coastal low clouds dissipate later on, the ozone in the mixed layer forms and tends to reach the same levels as it did aloft, earlier.

II INTRODUCTION

High ozone concentrations in northern San Diego County have caused concern and raised questions about the source(s) of this pollutant problem. In addition, the San Diego County Air Pollution Control District has been directed by the EPA to develop an emission control strategy which will "roll back" ozone precursor emissions (hydrocarbons and oxides of nitrogen) within the county so as to insure the oxidant air quality standard will be met in the future.

However, the normally present northwesterly winds along the San Diego County coast, as documented by various studies (Holzworth and Blake, 1957, Blake 1960, DeMarrais, et al 1965) caused some attention to be given to the possibility that oxidant pollution in San Diego may be the result of transport from the Los Angeles urban area to the north.

Subsequently, several airmass trajectory studies based on the limited ozone and meteorological data available for the coastal and off-shore island region indicated that the highest ozone concentrations experienced in northern San Diego County were due to long range transport of precursor emissions, particularly during "Santa Ana" wind conditions, (Brown 1975, Sklarew, et al 1975).

Obviously, if it can be demonstrated that high ozone concentrations in northern San Diego County are due primarily to the long range transport of ozone and its precursors from the Los Angeles area, then San Diego County's effort to prevent severe ozone pollution is highly dependent on Los Angeles' success in reducing its emissions.

It is generally understood that the Los Angeles polluted wake is transported off-shore, to the southwest, in the lowest several hundred feet during the northeasterly winds of a "Santa Ana" flow. It is also possible to visualize how these ozone precursor emissions could react photochemically under the influence of strong solar radiation to produce ozone during their overwater trajectory and subsequently be entrained in the next occurring sea breeze flow on-shore in the coastal areas to the south. This phenomenon has not been fully documented in terms of a three-dimensional description of the variations of wind, temperature and ozone concentration data in the Los Angeles - San Diego coastal and off-shore island region.

Three dimensional data over a period of time are essential to the construction of "backward air trajectories" from the points of high ozone concentrations to the precursor emission source regions. In addition, continuity of the data over an extended period of time is necessary to establish the frequency of various source-receptor trajectories and to discover other mechanisms for producing high ozone concentrations at long range from precursor emission source regions.

The purpose of this project was to investigate the extent and applicability of the over-water transport mechanism for delivering high ozone concentrations to the San Diego area.

The scope of this project included frequent wind soundings at four locations and an instrumented aircraft measuring the vertical and horizontal extent of the ozone cloud in the Los Angeles - San Diego coastal area on ten consecutive days (October 5-14, 1976) and detailed analyses of the data. This ten day period included a complete "Santa Ana" wind episode with occurrences of high ozone concentrations measured in northern San Diego County by the San Diego APCD surface monitoring network.

The report contains a description of the measurement equipment and techniques, including calibration procedures, detailed analyses of the data using vertical profiles, cross-sections, and airmass trajectories; selected color photographs of interesting visual observations; and conclusions and recommendations. All the basic data and analyses from the program are contained in a data supplement volume.

III EQUIPMENT AND PROCEDURES

A. Airborne

The aircraft used in this project was a Piper Twin Comanche. The temperature sensor and ozone sampling intake were located in the nose of the aircraft, away from the engine exhaust outlets under the wings.

The sampling intake line, 0.6cm teflon tubing, was kept as short as possible, to reduce the possibility of wall effects which could act to reduce the amount of ozone detected. The total length of the sampling line was about 3m.

Ozone was measured by a Dasibi 1003AH ozone monitor, factory modified to provide a reading update every 15 seconds.

Oxides of nitrogen were measured by a Monitor Labs ML8440 NO_x sensor, which gives continuous readings of both total oxides of nitrogen (NO_x) and NO.

The output from both the NO_x and O_3 monitors was recorded on a Rikadinki B381 strip chart recorder, operating at a chart speed of 1 cm per minute.

Inverters were used to obtain 115v power for the instruments, operating off the aircraft's power supply. One inverter (rated at 500w) was used to operate the Dasibi instrument and the recorder. Another 500w inverter served the Monitor Labs instrument. Shortly after the beginning of the operation this inverter failed. A substitute 1000w inverter was obtained, but proved to be defective. This resulted in only three hours of NO-NO_x data being obtained during the course of operations.

The temperature was measured by a Westemp Model ET2 portable temperature monitor. The output was read manually at 100 foot altitude intervals to 3000 feet and at 500 foot intervals thereafter.

B. Winds Aloft

The winds aloft were measured by optical theodolites (David White M6061), tracking 30 gram pilot balloons. The balloons were inflated to a standard free-lift condition which gave a rate of rise averaging about 600 feet per minute (3 mps) from surface to 5000 ft., (1.5km)

Observations were made at Long Beach Airport, South Carlsbad, Pacific Beach, and Black Jack Camp on Santa Catalina Island. The pilot balloons were tracked to 5000 feet (1.5km), or until they disappeared into the coastal low clouds. Tracking consisted of obtaining horizontal and vertical angle readings from the theodolites every 30 seconds. The theodolites were first oriented with respect to true north, so that all directional data is given in degrees from true north.

The winds at levels above the ground were obtained by plotting the balloon positions at each 30 second interval, with the wind being obtained graphically from the distance and bearing between successive one-minute balloon positions. This in effect provides an averaging process to eliminate variability that could occur if the 30 second positions were considered individually. The balloon heights were determined from time-height tables for the standard free-lift weighting procedure applicable to 30 gram balloons inflated with helium gas.

In addition to the four M_2S winds aloft locations, the wind aloft from the National Weather Service regularly scheduled sounding balloon runs at Los Angeles International Airport (0600 and 1200 PDT) and San Diego Montgomery Field (0500 and 1700 PDT) and from the Navy's special sounding balloon runs at San Clemente Island and Point Loma (0900 and 1400 PDT) were incorporated into the analyses. The special Navy sounding data were only available for the period through October 12, 1976, and because of the computer format used, gave no wind data below 1800 ft. (550 m).

C. Ground Based Ozone Monitoring

Ozone was measured by a Dasibi 1003AH ozone monitor at Happy Jack Camp in Santa Catalina Island. The sampling line, 0.6 cm teflon tubing, was about 1 m long with the opening positioned 2 m above ground. The output from the Dasibi was recorded on a Hewlett-Packard 680M strip chart recorder, operating at a one inch per minute chart speed.

D. Aircraft Operations

Winds aloft measurements were made every three hours during the day (0600, 0900, 1200, 1500, 1800 Pacific Daylight Time, PDT) and at 2300 PDT, for 10 consecutive days. Aircraft operations were planned to generally correspond to this schedule during the "intensive" portion of the study (the first six days) and twice a day for the remainder of the project.

Figure 1 shows the study area with the locations of the four winds-aloft observation sites and the general aircraft flight paths. Table I relates some of the pertinent letter identifiers in Figure 1 to geographic place names. The inland flight path was used during the deep marine layer condition and the overwater flights were used during the Santa Ana wind conditions.

The flight plan called for the aircraft to make a temperature and ozone sounding to 3000 or 4000 ft. seaward from Long Beach and then return to the elevation where the highest ozone concentration was noted while flying horizontally to the area offshore from Carlsbad. Usually a temperature and ozone sounding and multiple-traverses perpendicular to the coast for bag sampling were made in the area offshore from Carlsbad and from La Jolla.

TABLE I

Identifier	Location
AL	Alpine
AVX	Catalina Airport
BRN	Brown Field
CRQ	Carlsbad (Palomar Airport)
LGB	Long Beach Airport
MA	San Mateo Point
MYF	Montgomery Field
NB	Newport Beach
NUC	San Clemente Island
RA	Ramona
SAN	San Diego (Lindbergh Field)
SEE	Santee (Gillespie Field)

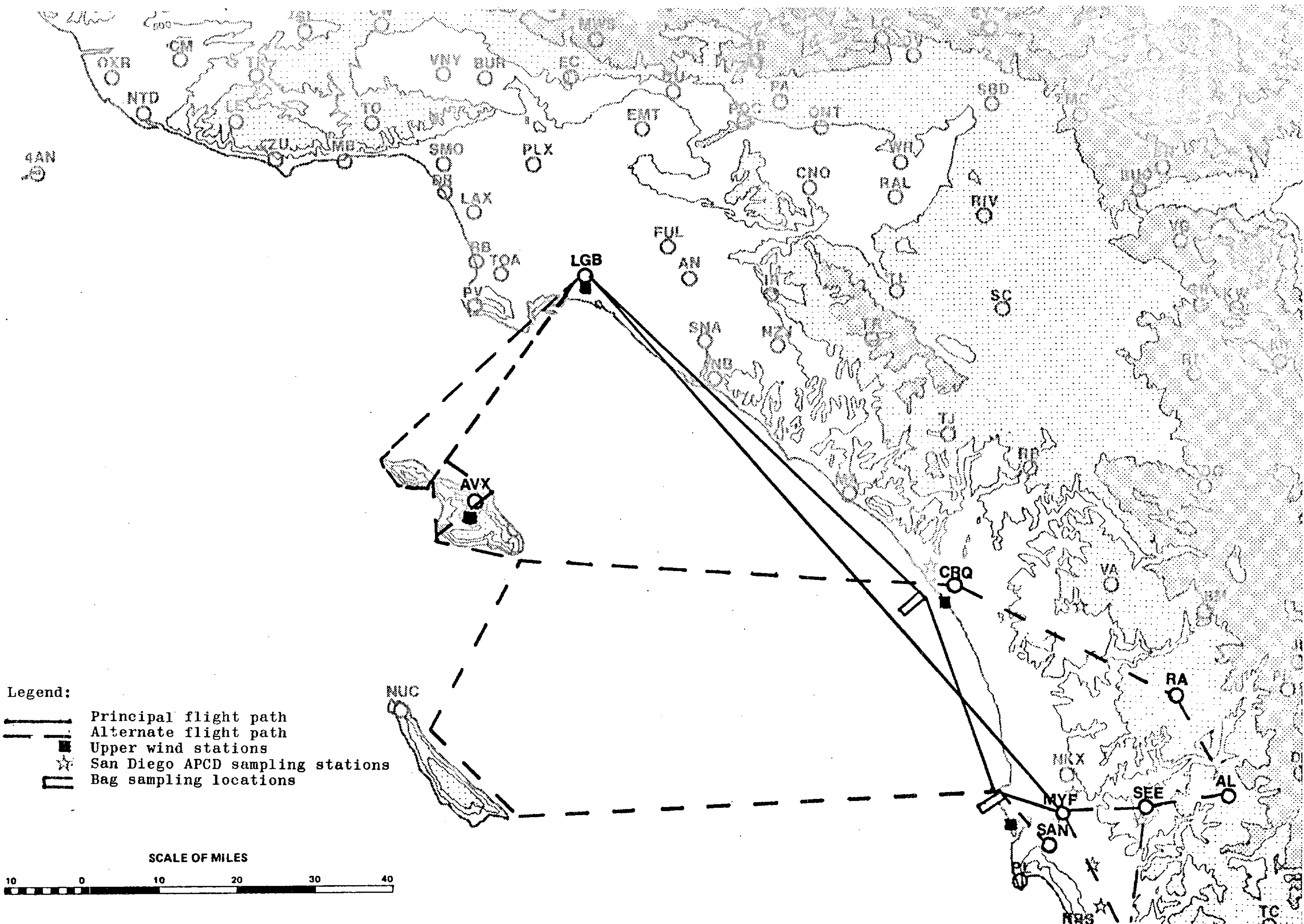

FIG. 1: Flight Paths and Station Locations

The first flight each day made a landing at Lindbergh Field for operational briefing purposes; subsequent flights used Montgomery Field for the San Diego landing point.

The bag samples were collected in 30 l Tedlar bags and were protected by black plastic sacks during the period between sampling and analysis. The analyses were performed by personnel of the San Diego APCD, using gas chromatography.

The return portion of the flight plan called for a repeat in reverse of the flight pattern from Long Beach to San Diego when Santa Ana wind conditions were present. However, when deep marine layer - onshore flow conditions occurred, the return portion of the flight path was modified to include soundings east of San Diego over Alpine and horizontal traverses from there to Carlsbad with the remainder of the flight path overwater to Long Beach.

An observer recorded the temperatures with height during the climbing and descending portions of the flight path and at select intervals during horizontal flight and took photographs of interesting visual phenomena. While the ozone was recorded continuously, the Dasibi ozone sensor operated on a cycling basis, providing an updated reading every 15 seconds. At the aircraft's cruising speed of 180 mph (288 kmph), this is equivalent to a sample every 0.8 miles (1.21 km). During climb and descent, the rate of altitude change was 300 feet per minute (1.5 mps).

Altitude information was derived from the aircraft's altimeter, which was corrected at both ends of the flight pattern by the altimeter settings reported at each airport.

E. Data Reduction and Analysis

1. Cross-sections

All air sampling, temperature sounding and wind data were placed on cross-sections to present a picture of a slice of the atmosphere as it existed between Long Beach and San Diego for each of the aircraft flight traverses. The cross-sections were analyzed for the high ozone layers encountered, the locations of the maxima being indicated by shading. Inversion bases and tops were also noted to establish the relationships between the stable air and the ozone rich layers.

2. Soundings

Temperature and ozone data were plotted in terms of height versus degrees F and parts per million, respectively. Occasional remarks on weather phenomena such as cloud top heights, were also noted on the sounding plots.

3. Steamline and Horizontal Ozone Distribution Maps

Streamline maps at the altitude of maximum ozone were prepared for the pilot balloon sounding times and the horizontal ozone distributions were added. These maps were prepared so as to permit construction of backward trajectories.

4. Trajectories

To answer the question, "Where does the high ozone aloft over the San Diego area come from?", a series of trajectory maps were prepared, using the techniques described by Sklarew, et al 1975, Neiburger 1955, and Meyer, et al 1976.

Backward trajectories were constructed in the following manner:

a. The high ozone air parcel speed and direction were extrapolated backward in time according to the speed and direction of the air flow as given by the preceding streamline charts until the trajectory either reached the Los Angeles area, ended up far out over water, or the trajectory reached the point where available charts were exhausted.

b. In certain cases, where decided subsidence or upward motion occurred, the trajectory altitude was changed accordingly to keep the air parcel within its environment just above the inversion base. In such situations, the winds at the appropriate levels were used in the trajectory construction process, and the actual height at a particular point is indicated on the trajectory.

In addition to these trajectories involving the tracking of ozone aloft, another series of maps were prepared which shows the trajectory analysis for times of maximum ozone readings at the San Diego APCD stations. In this latter series, both surface winds and winds at the level of the measured ozone maxima aloft were used, and the resulting trajectories compared.

The accuracy of the trajectory technique depends on the density of wind reporting stations and on the frequency of wind observations. The closer the air parcel of interest is to a data point, the more reliable is the derived trajectory.

The longer in time that a trajectory is extended the less accurate it tends to be, since any error in position at a given time could cause the computed trajectory to begin to deviate from the path of the real air parcel.

Therefore, in this report, short trajectories are considered more reliable than long ones; trajectories found within wind reporting networks are more reliable than those deduced for more remote areas.

Any specific trajectory is open to question regarding its absolute accuracy. The totality of trajectories, however, if a common origin or destination is shown, is a reliable tool in atmospheric analysis.

IV INSTRUMENT CALIBRATION, COMPARISONS AND DATA REDUCTION

The M_2S ozone and NO_x instruments were calibrated by the ARB before the project began. However, these calibrations were performed with the instruments removed from the aircraft, although an equivalent sampling tubing length was used to simulate the operational configuration.

A similar calibration was performed at the end of the project with respect to the ozone instruments. The NO_x instrumentation was not calibrated, since only a small amount of NO_x data, taken early in the project, was acquired.

During the course of the project calibrations were made on the aircraft instrumentation, in place, by the San Diego APCD.

Other comparisons were made, using a fly-by procedure with the M_2S aircraft wherein the plane passed directly over the two sampling sites on Catalina Island. Comparisons of the recorder traces at these times indicated that all instruments were responding in concert to ambient ozone levels.

One other comparison could be made. On October 9, 1976, the MRI aircraft was dispatched to follow a route from the Los Angeles harbor area to Catalina and thence to San Clemente Island, at a time when the M_2S aircraft was tracking ozone along a similar route, but in the opposite direction.

The two aircraft passed each other near the southeast tip of San Clemente Island. At their closest point of passage, the M_2S ozone reading was 0.11 ppm, compared to a 0.10 ppm for the MRI instrument.

However, shortly after this point, the MRI data showed different values for identical positions. For example, at MRI point 6, located at the SE end of San Clemente Island, an ozone reading of 0.175 ppm is deduced from the point 5 to point 6 print-out, while on the point 5E to 6 traverse a value of 0.14 ppm is given for point 6, from 6 to 6A, the point 6 value appears as 0.09 ppm. (See Blumenthal and Ogren, 1976)

The ozone data are presented without correction for pressure due to altitude changes. While theoretically a correction could be applied, (c.f. Cook and Bourke, 1976), the relatively low altitude levels of operation make this adjustment insignificant. (At most, a plus 16% correction would be applied for operation near 5000 feet, with about a 7% correction indicated at flight levels of 2500 feet.)

For the ground-based ozone station at the 1600 foot level of Catalina Island, the correction would be 6%. The highest hourly average value registered by this instrument, 0.13 ppm, would therefore be increased by 0.008 ppm, making the true reading 0.14 ppm, when rounded off. The maximum ozone detected by the aircraft, 0.32 ppm at 1000 feet, is correctable by the 0.01 ppm amount also. During the "Santa Ana" ozone episode (October 8-9, 1976), the ozone maximum was within 200 feet of the surface, so not even a 0.01 ppm correction is indicated.

V METEOROLOGICAL SETTING

The goal of the project was to conduct the field measurements during a "Santa Ana" wind condition. By delaying the start of the work until the unseasonable tropical disturbance-induced weather gave way to more normal October weather, operations were conducted over a period which started with a shallow marine layer, followed by a complete "Santa Ana" episode, and ending with the establishment of a moderately deep marine layer.

The field work began on October 5, 1976. A shallow marine layer was present over the Southern California coastal area with a ridge aloft building northward along the west coast (Appendix B presents the daily weather patterns at the surface and aloft from the National Weather Service Daily Weather Maps).

On October 6, 1976, the ridge aloft developed a cut-off high pressure cell centered over all of California while the surface pressures remained essentially the same. The marine layer along the coast from Long Beach to San Diego remained relatively shallow again throughout the day.

On October 7, 1976, the high pressure cell aloft split into two separate cells and the ridge moved slightly eastward. At the surface, a closed low was located just off the coast near the California - Oregon border. The marine layer became very shallow on this day along the coast, and some exposed areas were being affected by the beginnings of a strong down-slope flow of air - the "Santa Ana" wind.

On Friday, October 8, 1976, the marine layer became extremely shallow along the coast with indications of a second inversion layer near 1500 feet in the San Diego area in the early evening. The two cut off high pressure cells aloft were replaced by a single open high contour with the ridge displaced even farther eastward. A minor open low at the surface was located between Los Angeles and San Diego. The northeasterly "Santa Ana" winds were evident over all of Southern California.

On October 9, 1976, the high contour aloft closed again, but with a lower height than on previous days, and the ridge broadened as the long wave trough ahead of it moved over the Ohio River Basin. The surface showed slightly lower pressures, but no disturbance nearby. The marine layer remained extremely shallow.

The ridge aloft weakened considerably and the closed high contour disappeared completely on October 10, 1976, while at the surface a low pressure disturbance was located over Northern California. The marine layer increased in depth along the coast during the day, becoming nearly as deep as it was at the beginning of the field work on October 5, 1976.

On October 11, 1976, a trough began to develop aloft over the western United States and a thermal low appeared over the lower Colorado River area between California and Arizona. The marine layer along the coast remained relatively shallow throughout the early morning to mid-afternoon period for which observations were made.

On October 12, 1976, the trough aloft reopened south and formed a cut off low over the California - Arizona border while at the surface the trailing edge of a weak cold front moved through the Southern California area. The marine layer became deeper, similar to the situation during the first two days of the project.

The pattern aloft developed into a cut off high contour over Northern California and a cut off low contour over southern Arizona on Wednesday, October 13, 1976. At the surface, pressures rose to their highest level during the field project. The marine layer along the coast from Long Beach to San Diego became decidedly deeper by mid-afternoon at the conclusion of the day's observations.

On October 14, 1976, the pattern aloft developed into the classic "omega" pattern of adjacent high and low contours along a northwest-southeast orientation while the pressures at the surface dropped to the more typical levels present during most of the field project. The marine layer along the coast continued to deepen through the late afternoon on this day, which concluded the field project.

VI OZONE TRANSPORT RESULTS

A. The "Santa Ana" Case

Beginning on October 7, 1976, the developing off-shore flow over Southern California affected the location and magnitude of the SCAB "smog" cloud. While on prior days the surface ozone distribution maps indicated values of greater than 0.20 ppm to the eastern edge of the Los Angeles Basin, (Fig. 2) on the 7th the high concentrations were restricted to the coastal and central valley sections of the Basin. (Fig. 3)

By the 8th of October, the off-shore flow in the SCAB was even more pronounced, and relatively low values of maximum ozone were experienced, occurring late in the day as the sea breeze flow pushed the aged smog cloud back on-shore (Fig. 4). The maximum effect, in terms of highest ozone concentration, was noted at Oceanside, where a 0.21 ppm reading was detected at 1400 PST.

The over-all maximum in the San Diego County area occurred October 9, 1976, when a maximum of 0.29 ppm was noted at Oceanside (Fig. 5). Only a small regime of 0.15 ppm values was noted in the Pasadena-Burbank area of the Los Angeles Basin.

The "Santa Ana" ended on October 10, 1976, with the beginning of southerly flow along the coast during the afternoon. The surface ozone maximum occurred again at Oceanside station, reaching 0.18 ppm at 1400 PST. (Fig. 6)

The described "Santa Ana" condition was accompanied by strong subsidence with temperatures of 90°F (32°C) aloft; the entire inversion layer being within 1000 ft. (300 m) of the surface. (Fig. 7)

The coast-line extent of the ozone pollution cloud existing on the afternoon of the 9th can be seen in Fig.8,

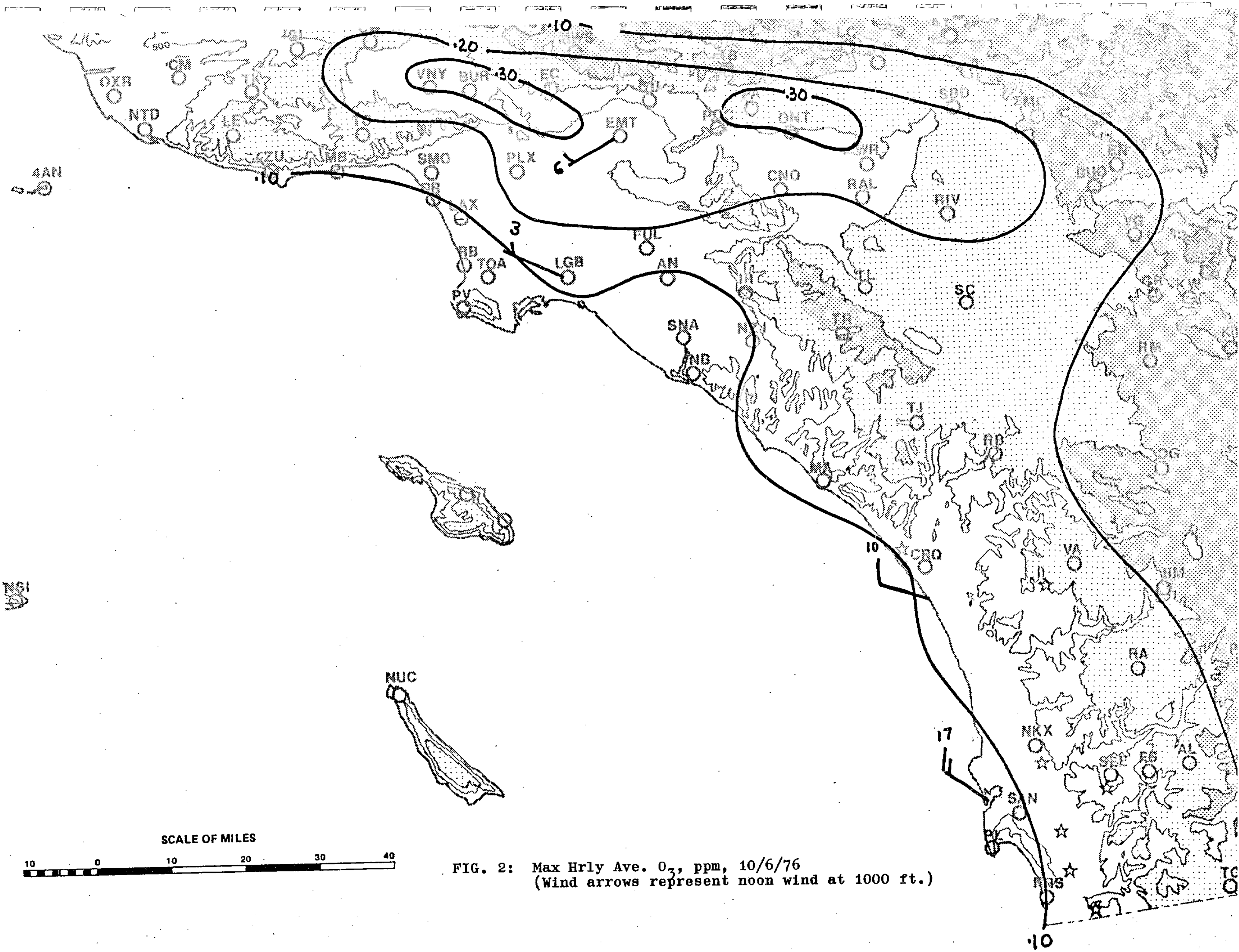

FIG. 2: Max Hrly Ave. O_3, ppm, 10/6/76
(Wind arrows represent noon wind at 1000 ft.)

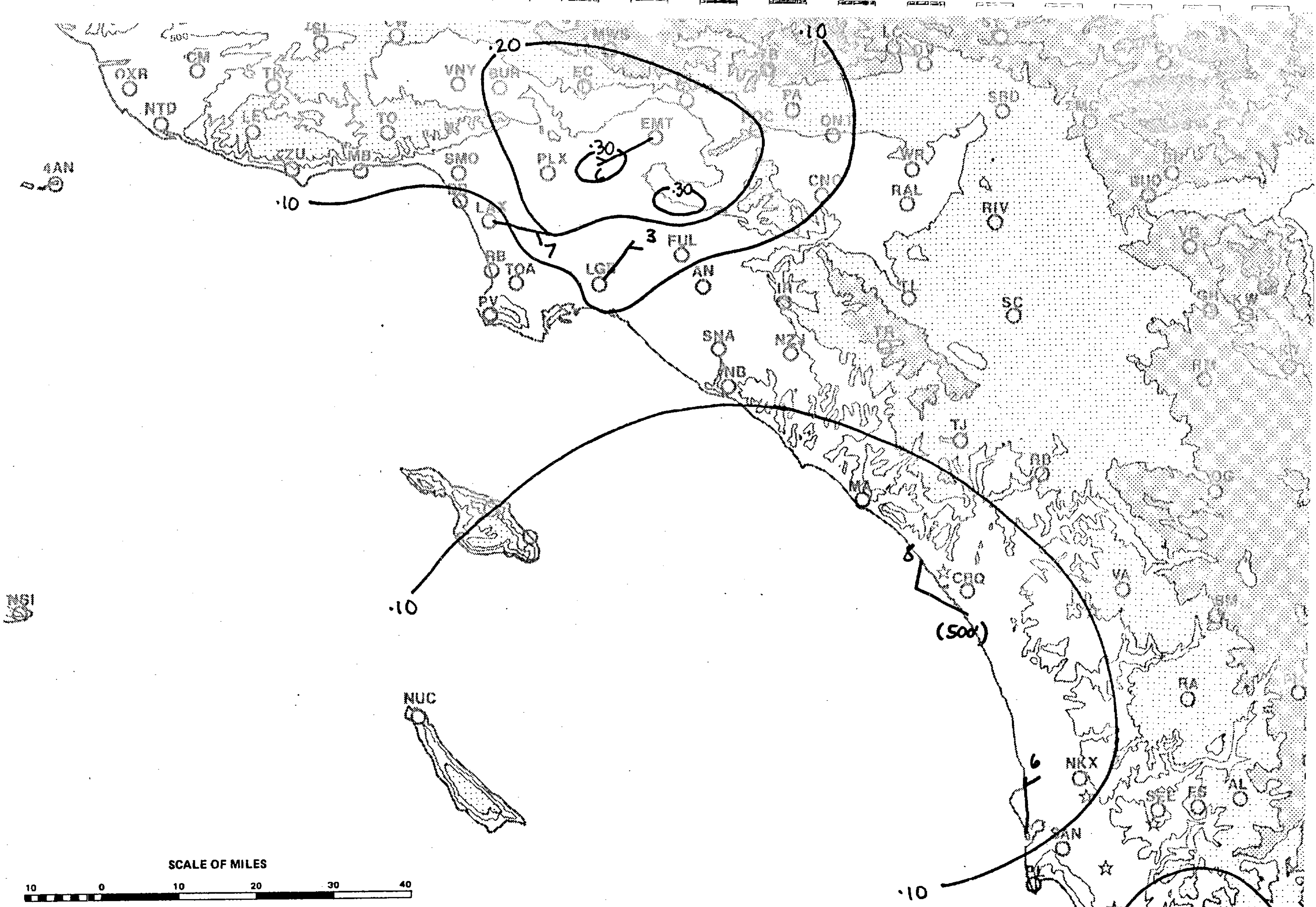

FIG. 3: Max. Hrly Ave. O_3, ppm, 10/7/76
(Wind arrows represent noon wind at 1000')

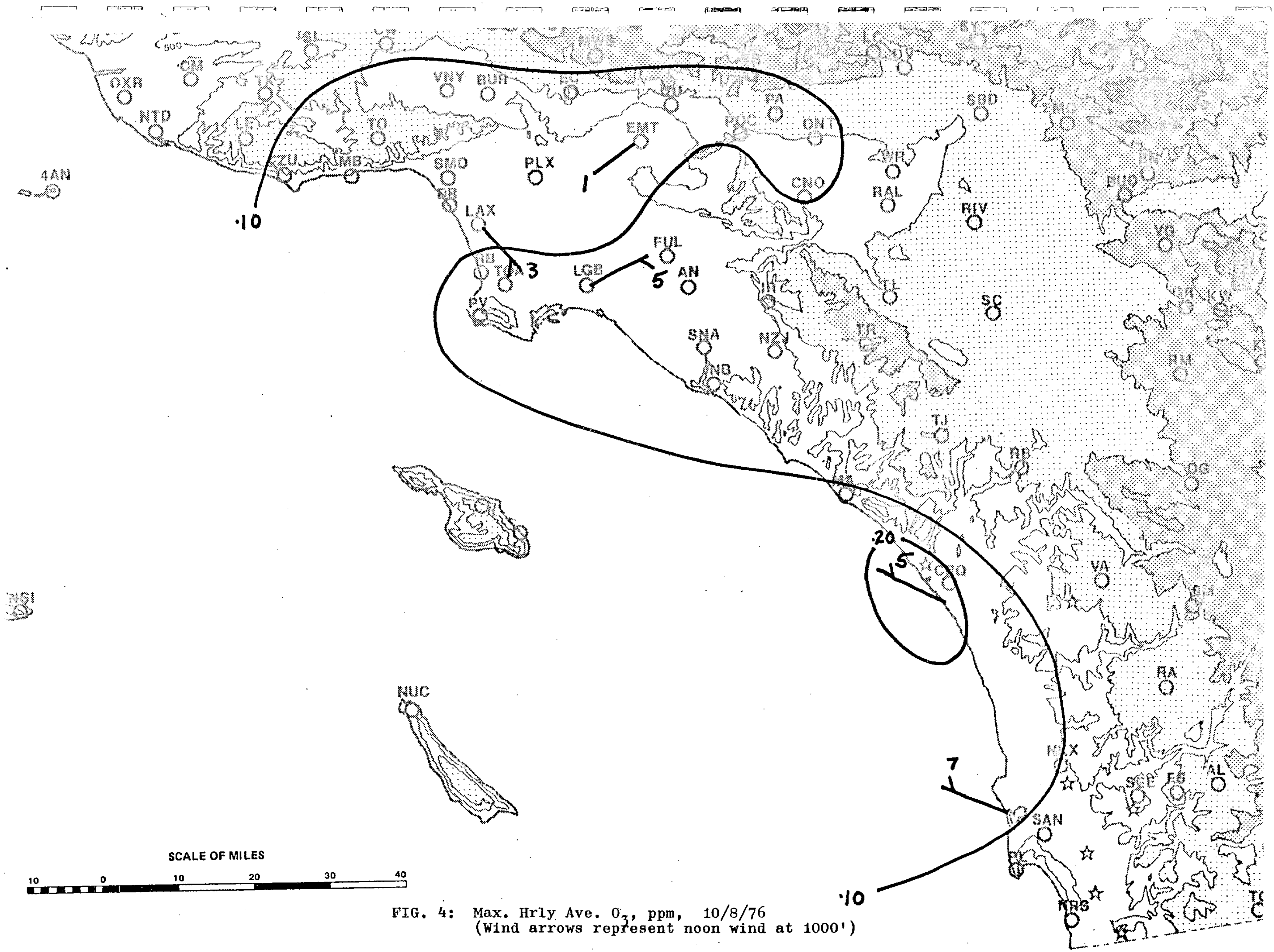

FIG. 4: Max. Hrly Ave. O_3, ppm, 10/8/76
(Wind arrows represent noon wind at 1000')

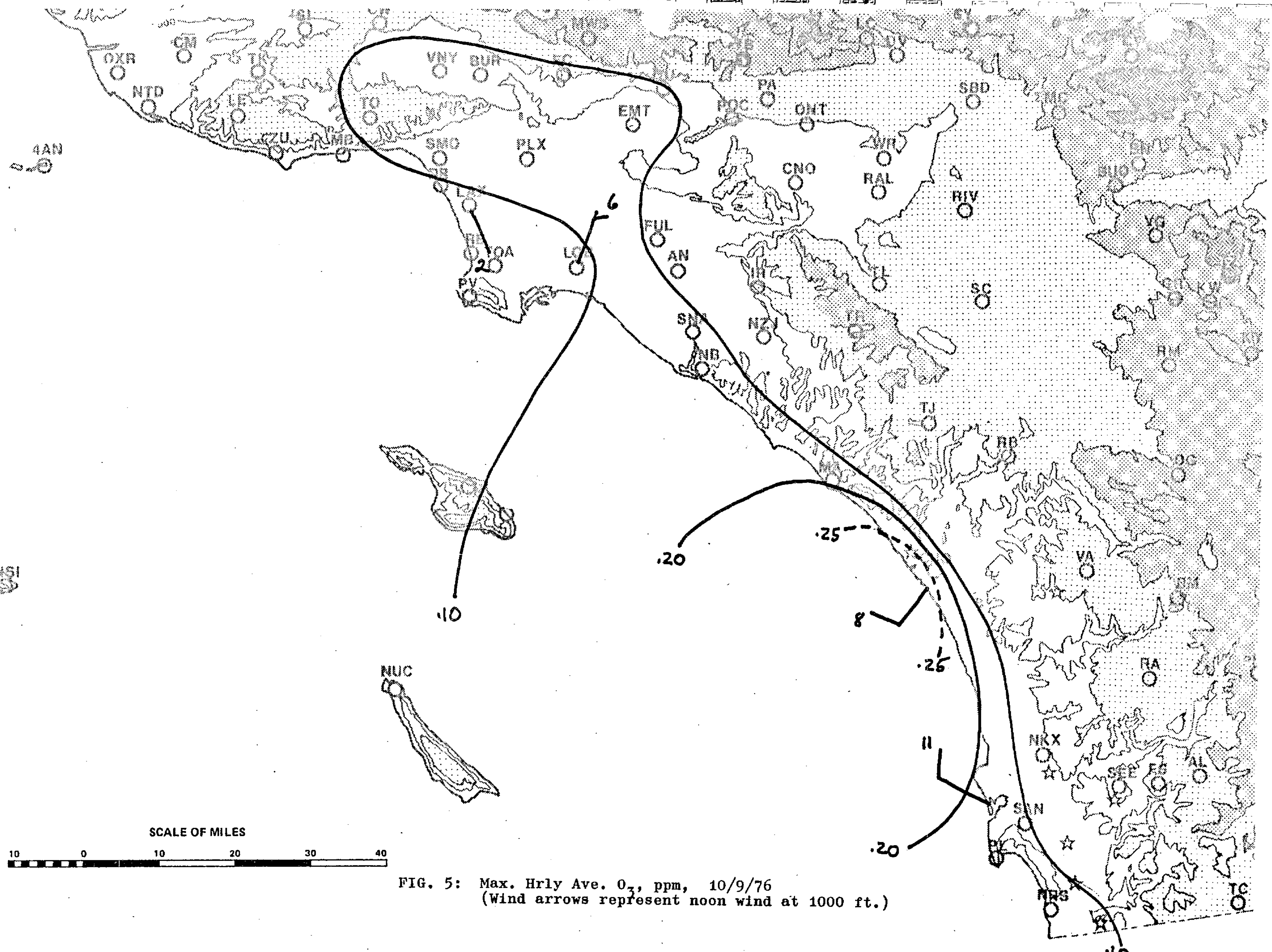

FIG. 5: Max. Hrly Ave. O_3, ppm, 10/9/76
(Wind arrows represent noon wind at 1000 ft.)

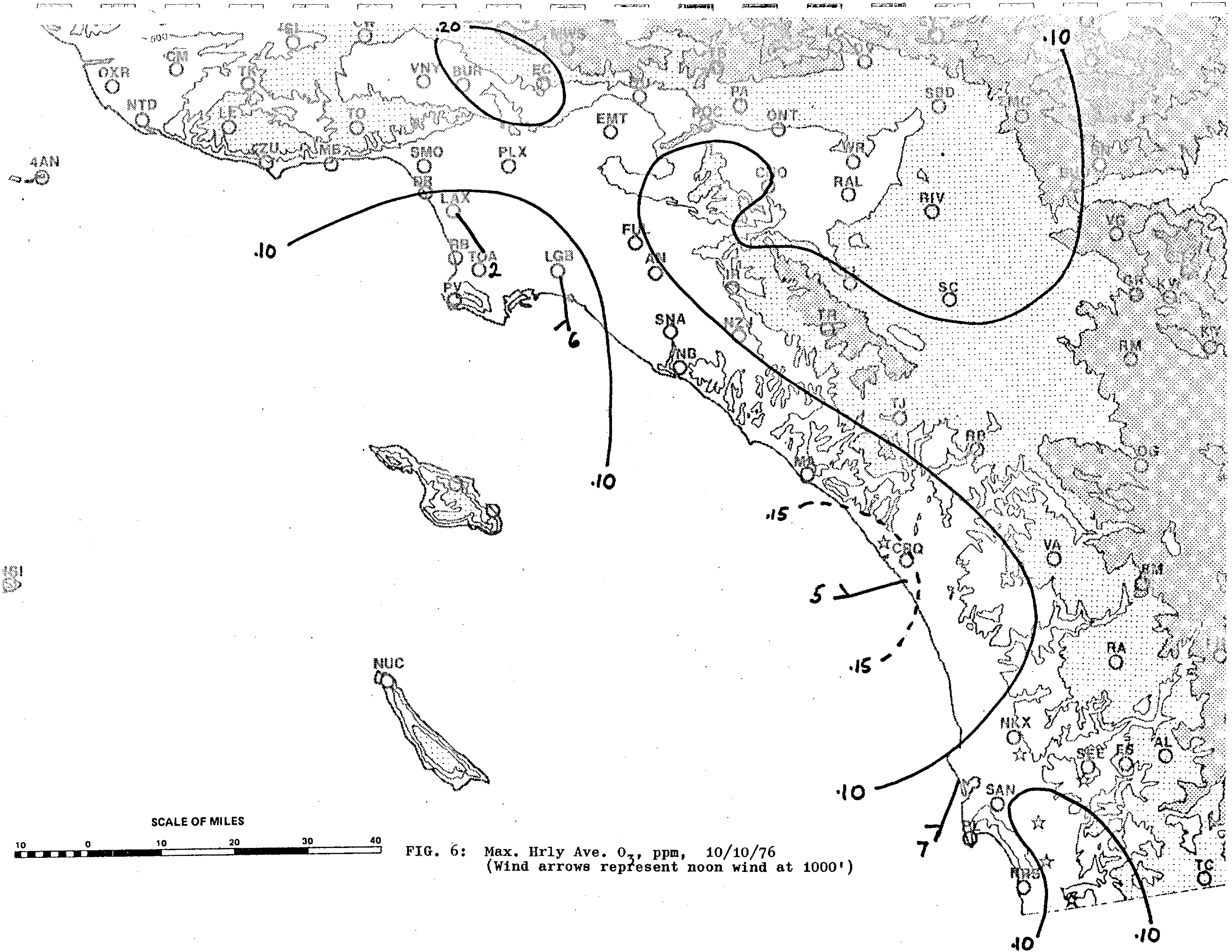

FIG. 6: Max. Hrly Ave. O_3, ppm, 10/10/76
(Wind arrows represent noon wind at 1000')

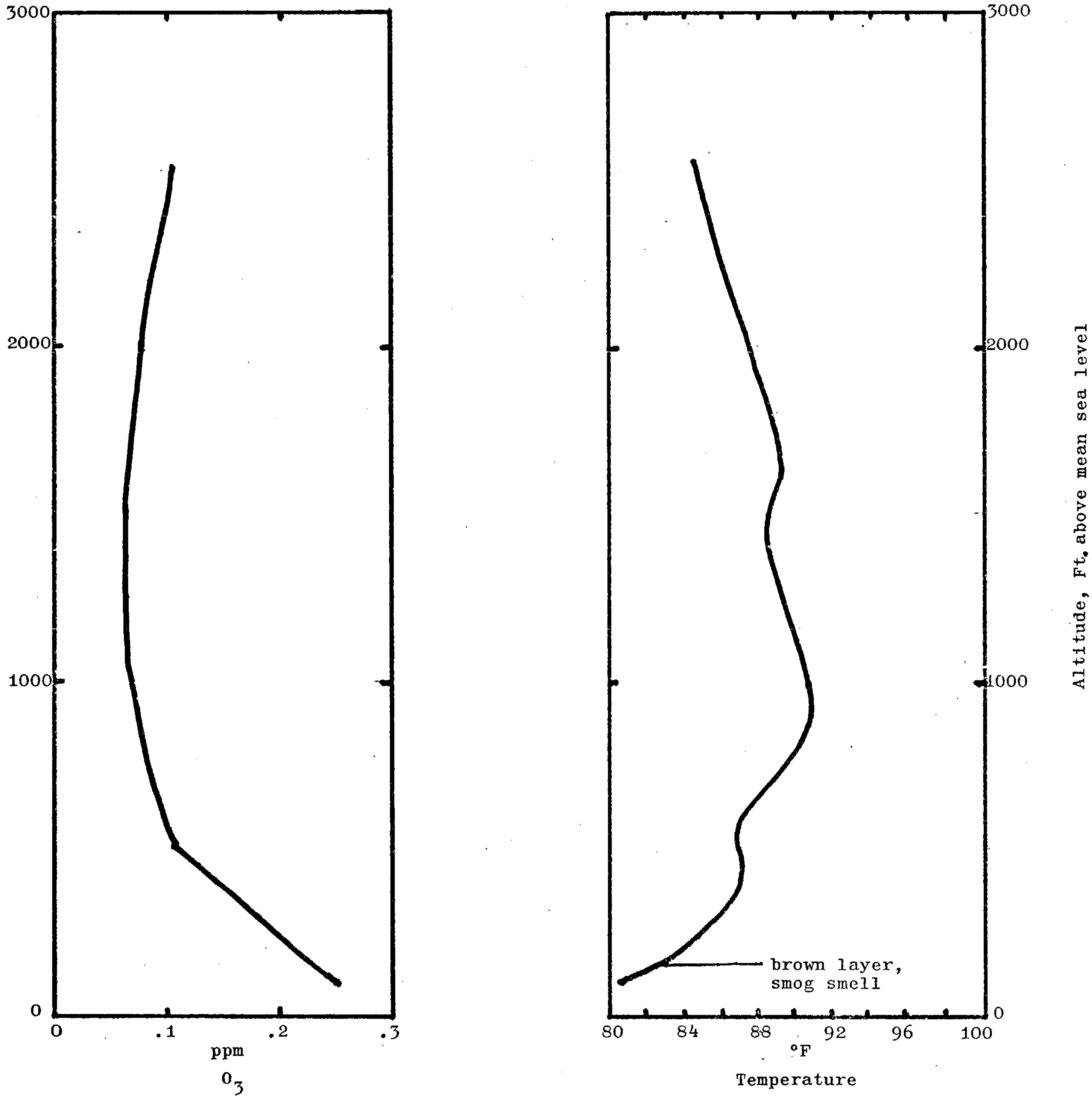

FIG. 7: Temperature, Ozone Sounding
off Encina, 10/8/76 1628 PDT

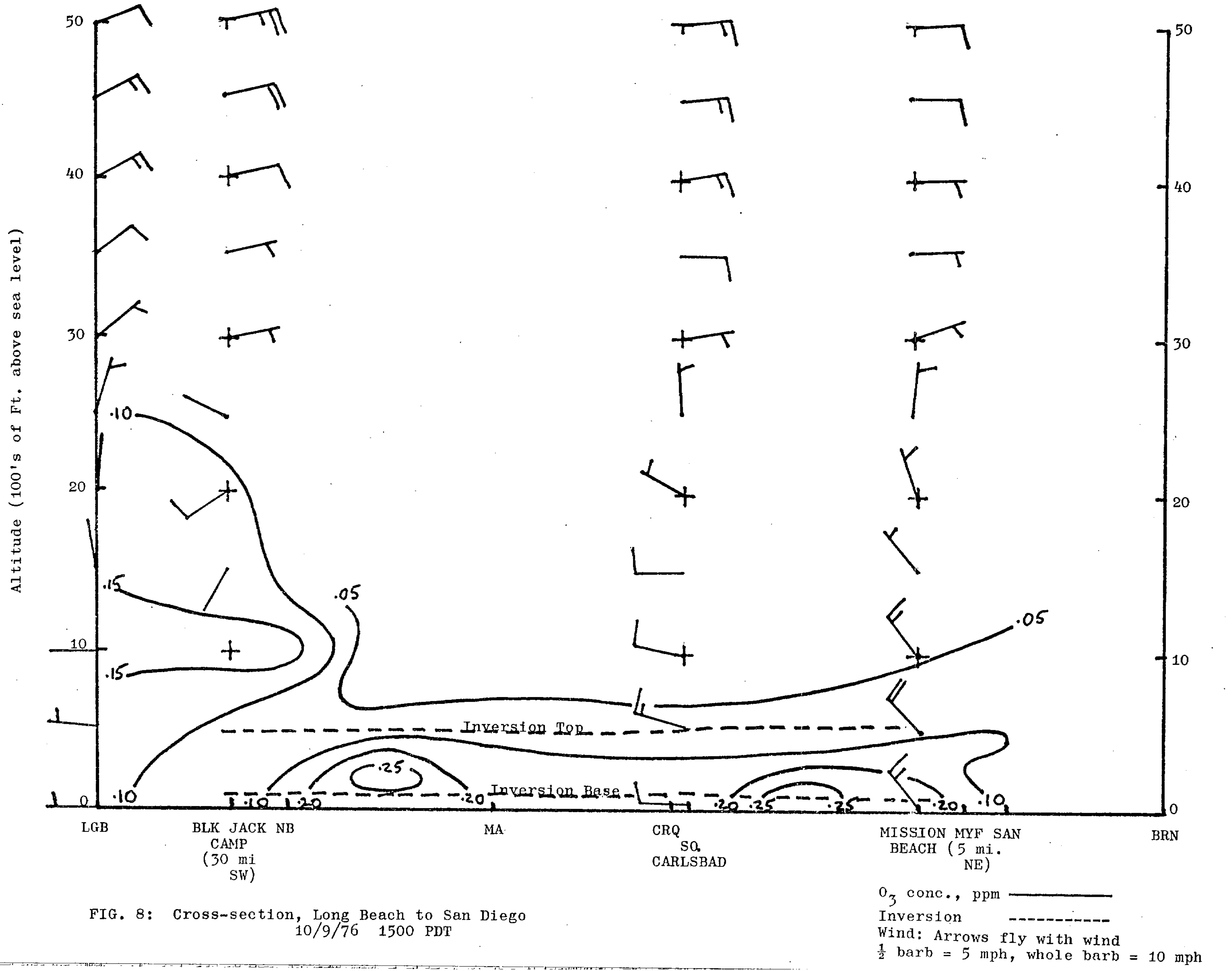

FIG. 8: Cross-section, Long Beach to San Diego
10/9/76 1500 PDT

a cross-section taken between Long Beach and San Diego. This slice of the atmosphere shows two kinds of ozone clouds. The first is the low level, high concentration one associated with transport over the sea. The second, located at about 1000 ft. (300 m) in the Long Beach-Newport area, represents the reacted cloud carried aloft over the coastal SCAB, due to instability that manages to put the pollutants above the surface-based inversion but not out of the stable layer above. This cloud is carried along the coast by a northwest wind, so that by evening the material aloft is detected as far south as San Mateo Point. (Fig. 9) The ozone aloft in the Long Beach area has, by this time, increased due to the movement of the reacted pollution cloud back to the coast from the inland portions of the SCAB at levels above 2000 ft (600 m).

Figures 8 and 9 also show the characteristic of northwesterlies at the surface, overlain by the "Santa Ana" (easterly) flow aloft. In Fig. 9 the northwesterlies extend to 1500 ft (450 m) over Long Beach, increasing in depth southward, to 2500 ft (760 m) over the San Diego area.

Aircraft tracking of the low-lying smog cloud between the mainland and Santa Catalina and San Clemente islands indicated that the polluted air mass extended to the islands. (Its seaward extent beyond the islands is unknown, since the M_2S aircraft's track did not include these areas.) Figure 10 shows a plot of the ozone cloud as it existed on October 9, 1976 at 1500 PDT (1400 PST). The low level (surface) wind flow is shown by the solid streamlines, while the ozone concentration values are given by the dashed lines.

The general picture which emerges from Figure 10

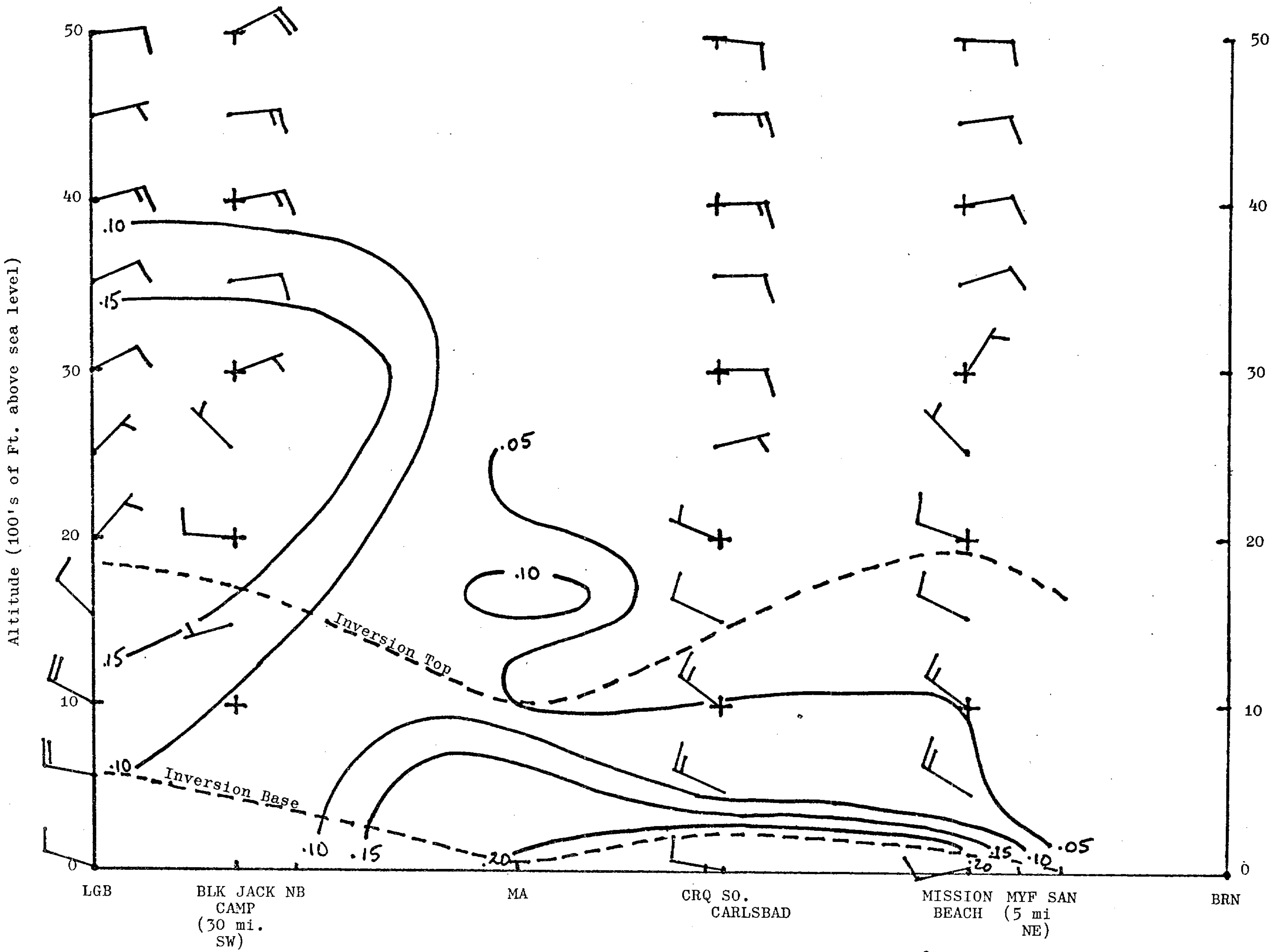

FIG. 9: Cross-section, Long Beach to San Diego
10/9/76 1800 PDT

O_3 conc., ppm ————
Inversion - - - - - -
Wind: Arrows fly with winds
½ barb = 5 mph, whole barb = 10 mph

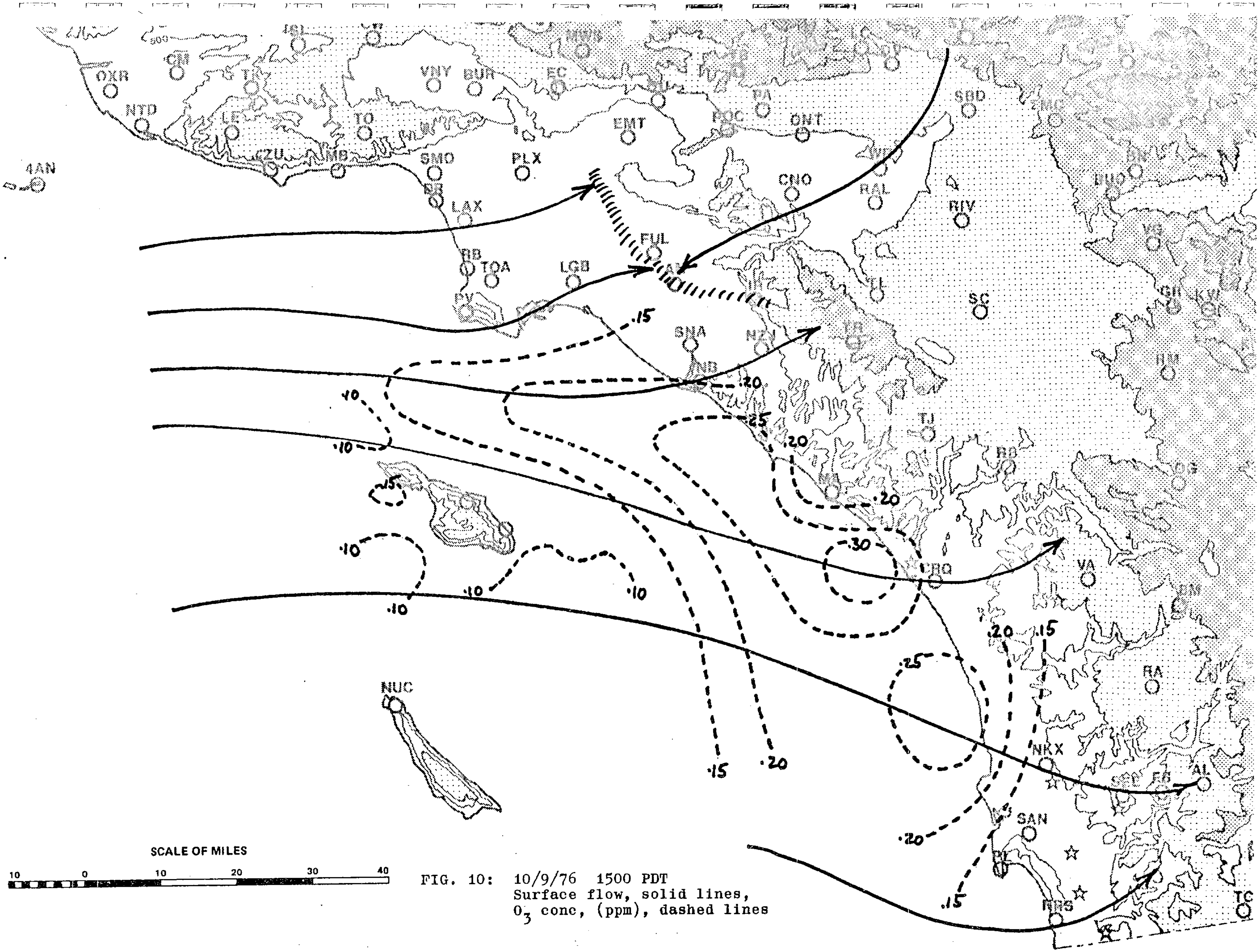

FIG. 10: 10/9/76 1500 PDT
Surface flow, solid lines,
O_3 conc, (ppm), dashed lines

is that of an aged photochemical pollution cloud lying over the coastal waters of Southern California, just beginning to return on-shore with the prevailing on-shore breeze, with its point of maximum effect well south of the SCAB.

That the observed ozone maxima in the northern San Diego County coastal area are the result of transport from the SCAB can be seen from Figures 11-14, which show the trajectories of the air parcels with the high concentration of ozone found off Oceanside on each of the days in this "Santa Ana" period.

These backward trajectories are based on the winds aloft data taken at three hourly intervals, plus the hourly wind reports from the surface-based weather stations located in the Southern California coastal area. Because of the dense network of wind reports along the coast, the derived trajectory for each day is thought to be very close to the actual path taken by the air mass in question. (Actual streamline maps from which trajectories were constructed are given in Volume II, Appendix J.)

Shown on the trajectories are locations of ozone measurements made at indicated times, offset from the trajectories by distances as given by dashed lines. In the case of the October 9, 1976, 1500 PDT trajectory, the ozone value at 1200 PDT, three hours prior to its detection off Oceanside was about 0.17 ppm, while at 0600 PDT, the ozone value was recorded as zero, indicating a fresh primary pollutant cloud existing off the northern Orange County coast.

The development of a strong ozone maxima, starting from ozone levels below natural backgrounds (due to scaveging of ozone by the primary pollutant NO), to its

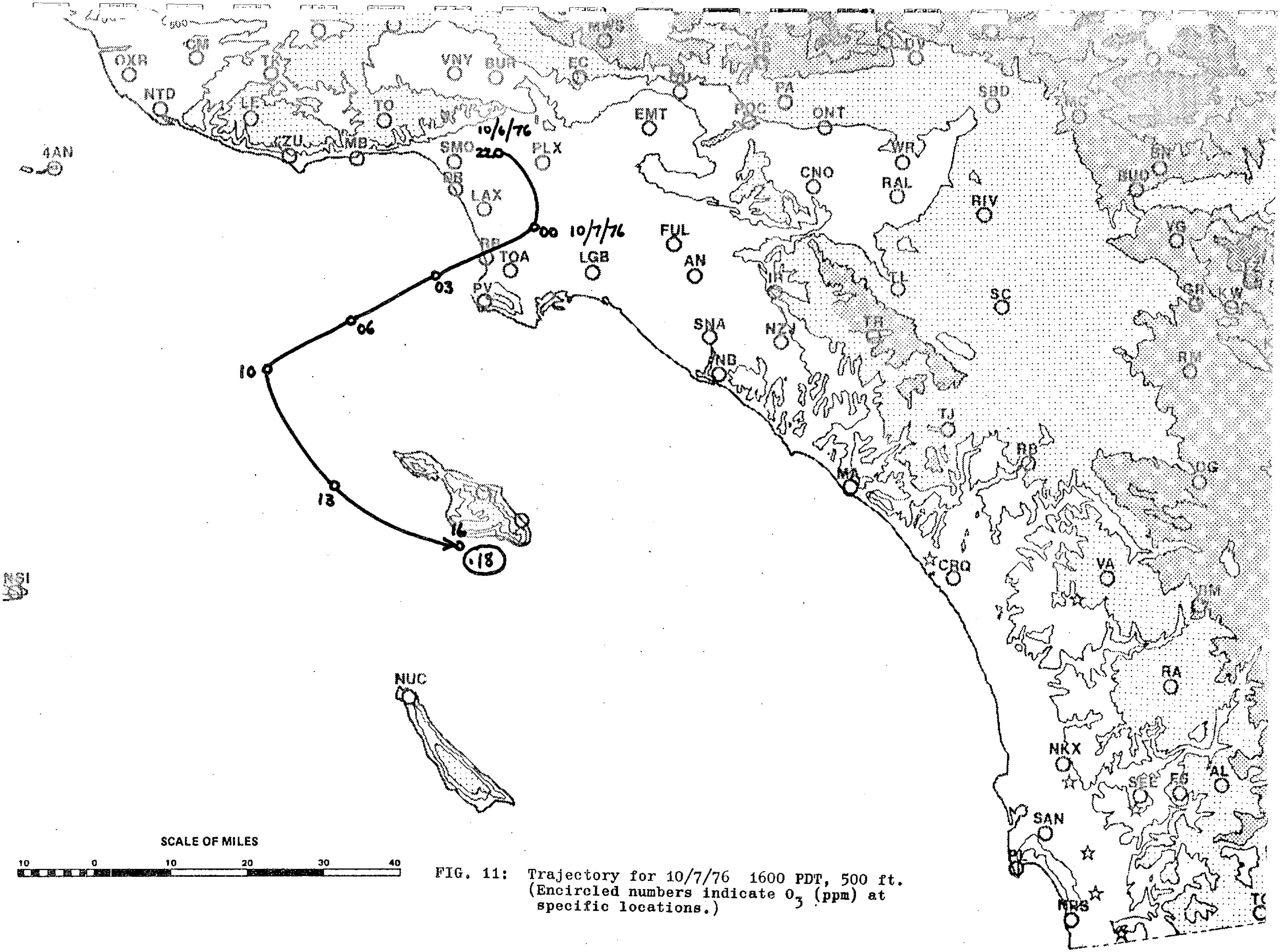

FIG. 11: Trajectory for 10/7/76 1600 PDT, 500 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

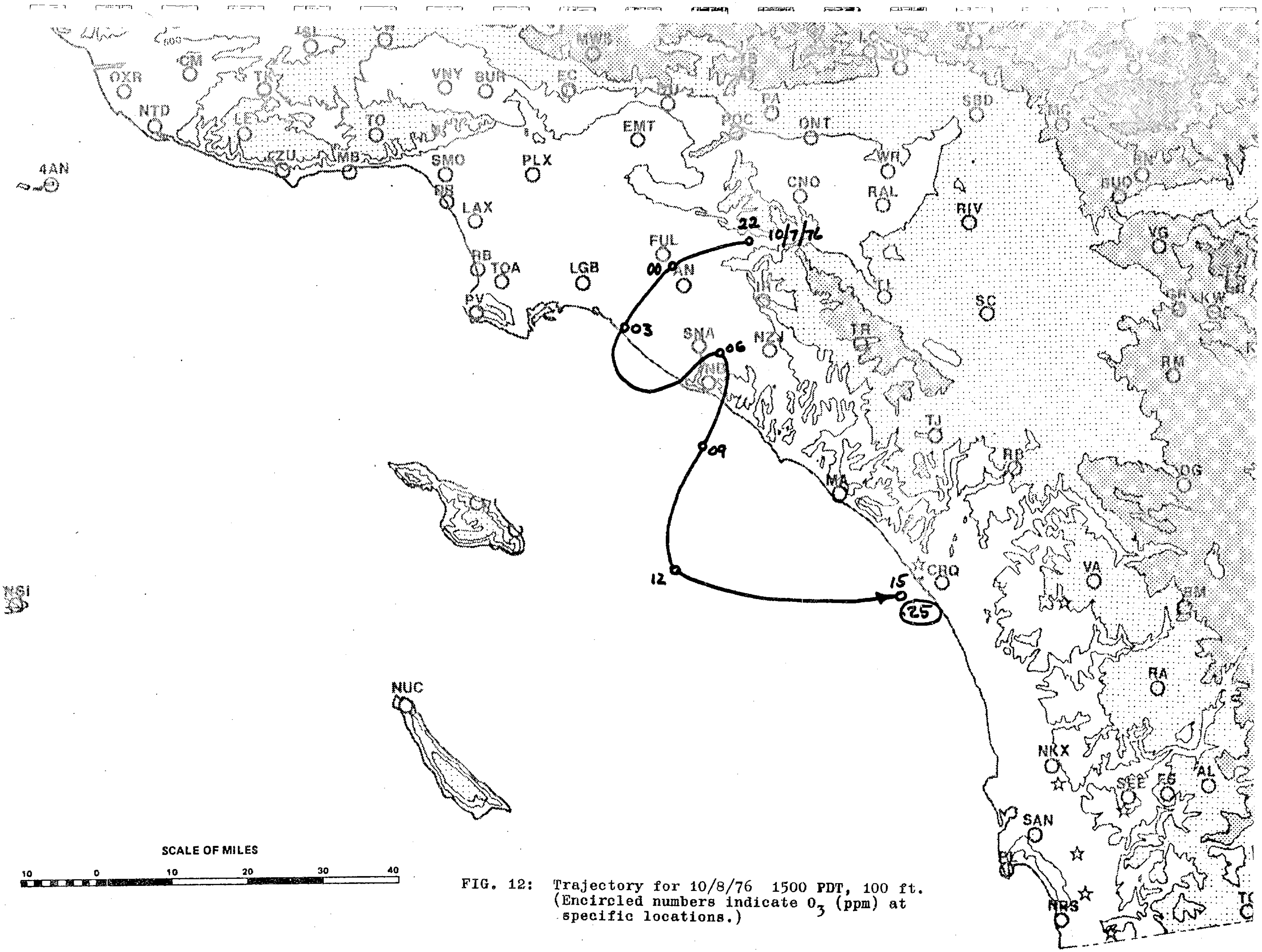

FIG. 12: Trajectory for 10/8/76 1500 PDT, 100 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

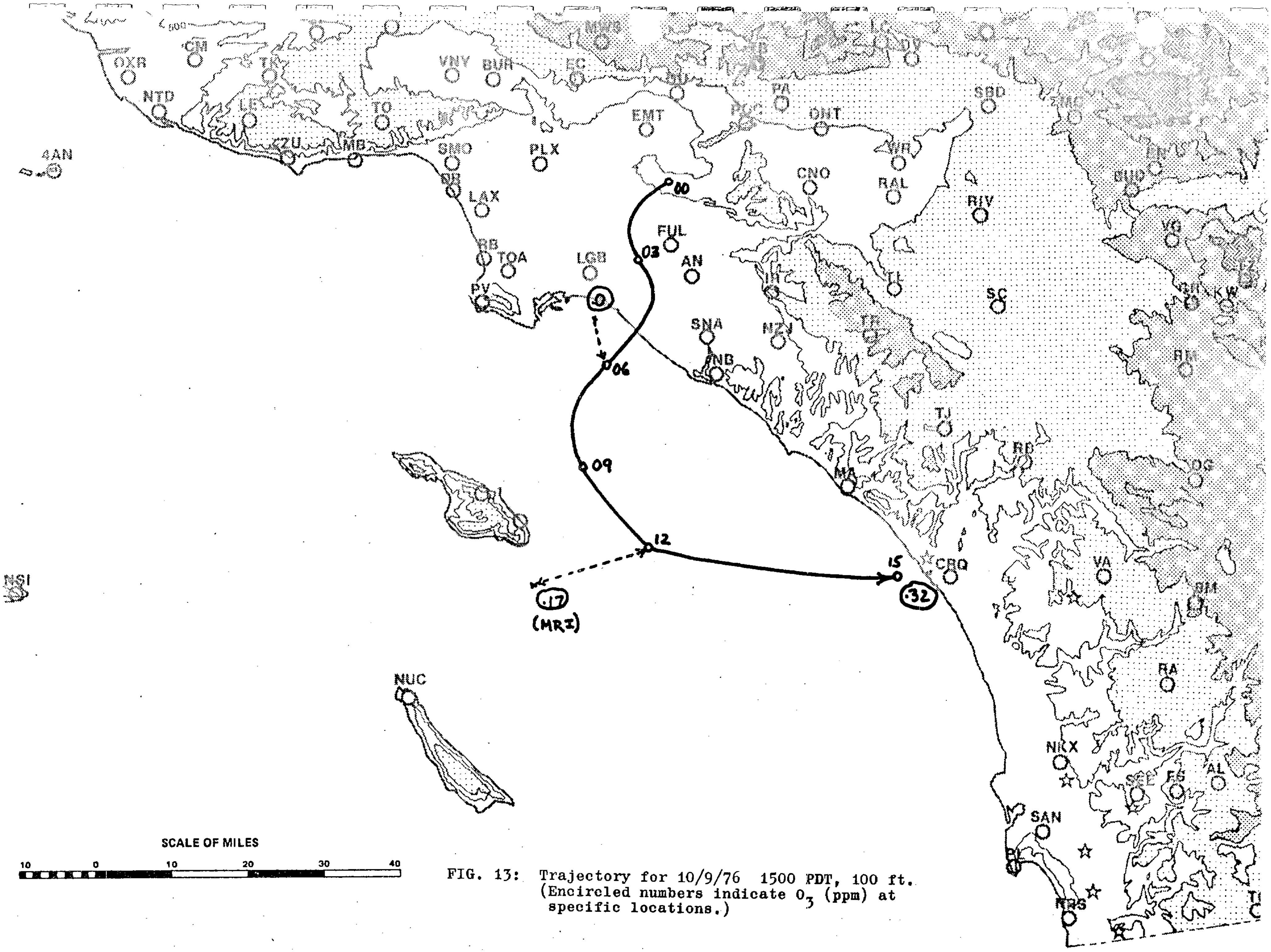

FIG. 13: Trajectory for 10/9/76 1500 PDT, 100 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

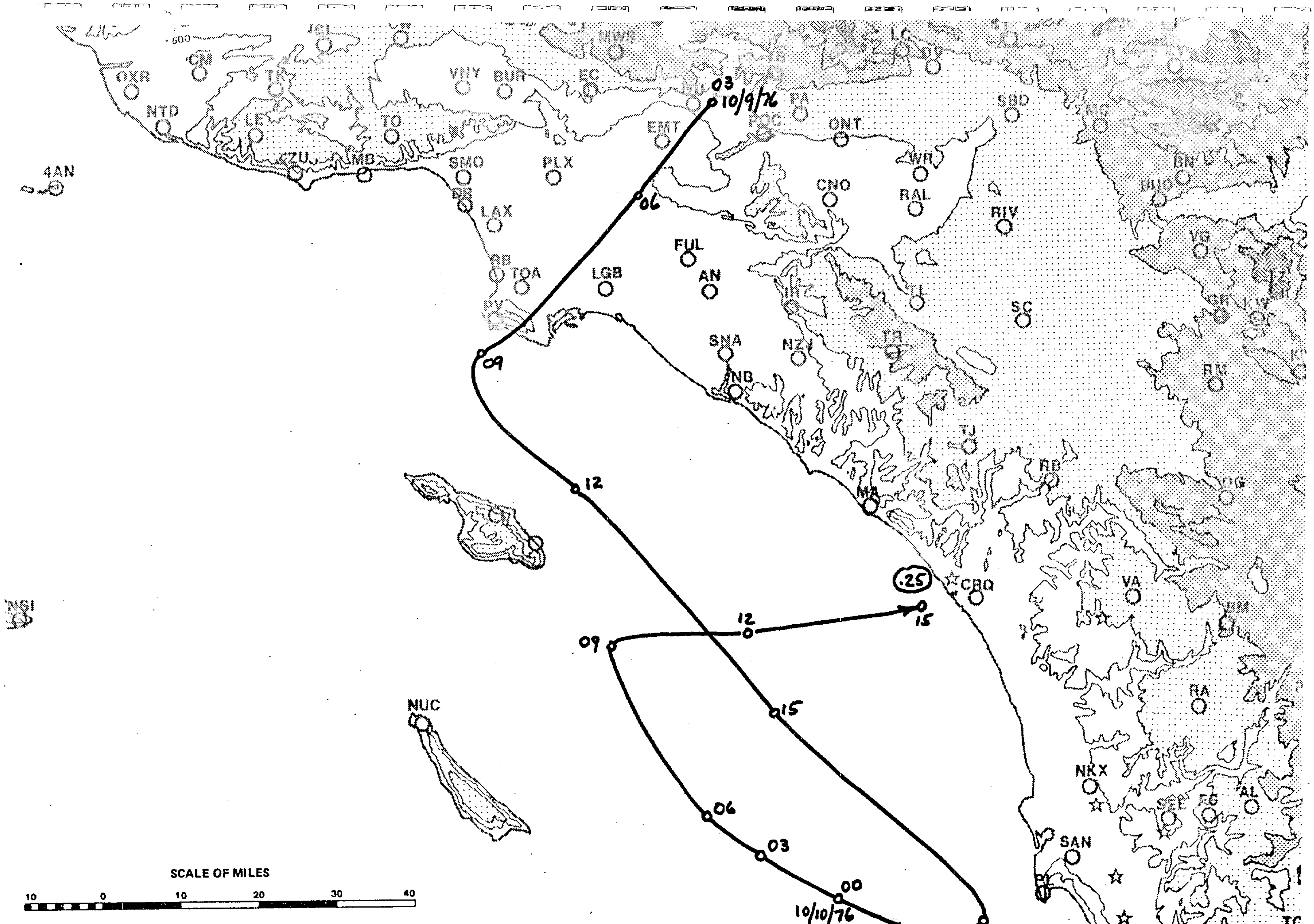

FIG. 14: Trajectory for 10/10/76 1500 PDT, 500 ft. (Encircled numbers indicate O_3(ppm) at apecific locations.)

ultimate value as it reaches shore is enhanced by the strong subsidence associated with the "Santa Ana", (keeping a vertical restraint on the smog cloud) and the lack of mixing over the relatively cold ocean surface. This, together with ultra violet radiation acting on the pollution through an atmosphere completely lacking in clouds or fog, represents the optimum conditons for high ozone concentrations.

It was on this day, during the aircraft track from San Diego to San Clemente Island, that the extreme ozone gradient associated with the top of the surface-based ozone layer was noted.

At 200 ft (60 m) the ozone recorder registered 0.08 ppm; at 180 ft (55 m), the ozone was 0.18 ppm. The aircraft was directed to undergo a series of climb and descents of this magnitude, and the ozone values were found to vary over the 0.08 to 0.18 ppm range.

The well-developed "Santa Ana" flow conditions on October 8th and 9th, which brought ozone levels to above 0.20 ppm at Oceanside, were documented by the instrumented aircraft, with a very close agreement between the maximum reported by the aircraft and by the San Diego APCD sampling station: for example, on the 8th, the aircraft, flying at an altitude of 100 ft (30 m), reported a maximum value of 0.25 ppm at 1400 PST; on this day the Oceanside station recorded a maximum hourly average of 0.21 ppm. On the following day the aircraft, again at 100 ft (30 m) off the surface, recorded a maximum of 0.32 ppm at 1400 PST, while the Oceanside station had a 0.29 ppm as a maximum hourly average, occurring at 1600 PST.

As shown in Figures 11-14 the SCAB origin of air parcels detected over San Diego County locations is quite evident. On the third day of the Santa Ana Case, (Fig.14) when the "Santa Ana" flow was beginning to give way to a southerly pattern, the trajectory constructed from the wind flow maps is more complicated, so some questions may be asked regarding the reliability of this analysis. Figure 14 indicates the SCAB as the origin of the 0.25 ppm ozone maximum detected off-shore Carlsbad. However, it also appeared to come close to the San Diego coast at about 1800 PDT on October 9, 1976. It could be argued that the pollution was introduced at this time, and therefore represents a case of the San Diego source region in action.

Since the aircraft was operating in this off-shore area the evening of October 9th, it is easy enough to check the nature of the lower atmosphere at that time. The data show that this off-shore air was rich in ozone - 0.22 ppm value at 300 ft (100 m) off Carlsbad, a range from 0.22 to 0.12 ppm off La Jolla between 100 and 500 ft (30 - 150 m). At this time, too, the air inland from the San Diego shoreline ranged from 0 to 0.05 ppm between the surface and 500 ft (150 m).

It appears not a likely prospect that San Diego's evening traffic source could have produced such high ozone values, given the low level of solar radiation available at the time in question. The low ozone values detected over San Diego probably better reflect the evening traffic source there.

On balance, it therefore seems more likely that the October 10, 1976 trajectory represents another instance of the SCAB source affecting the SDAB. Taken together, the "Santa Ana" flow days studied in this current project point to the conclusion that under "Santa Ana" conditions, the high ozone values detected in northern San Diego County are the result of primary pollutants introduced into a very stable air mass by sources in the SCAB. This substantiates the conclusions of studies by Brown (1975) and Sklarew, et al (1975), done for previous instances of "Santa Ana" flows associated with high ozone concentrations in San Diego County.

B. The Marine Layer Case

The previously discussed "Santa Ana" air flow case was sandwiched between two periods of what might be termed normal summer conditions. That is, the coastal area was overlain by a well-mixed air mass, the so-called marine layer, capped by an inversion. Characteristic of these conditions is the presence, especially during the night and morning hours, of a deck of stratus clouds.

The first period, starting with the beginning of field operations on October 5, 1976, showed a gradual lowering of the capping inversion, leading to the "Santa Ana" condition by the end of October 7, 1976.

Trajectories for air parcels corresponding to the ozone maxima aloft detected by the aircraft are shown in Figures 15 to 20.

While the height of the ozone maximum varied from day to day and, within a smaller range, from hour to hour, the calculated trajectories, based on the winds at the altitude of the observed ozone peaks, all show origin in or near the SCAB.

The second series of measurements made during marine layer situations followed the "Santa Ana" case previously discussed. During the period of October 11 through October 14, 1976, the inversion was gradually rising.

When trajectories were constructed backward with time, those associated with the maximum ozone aloft on October 11, 1976 showed a complicated route of travel

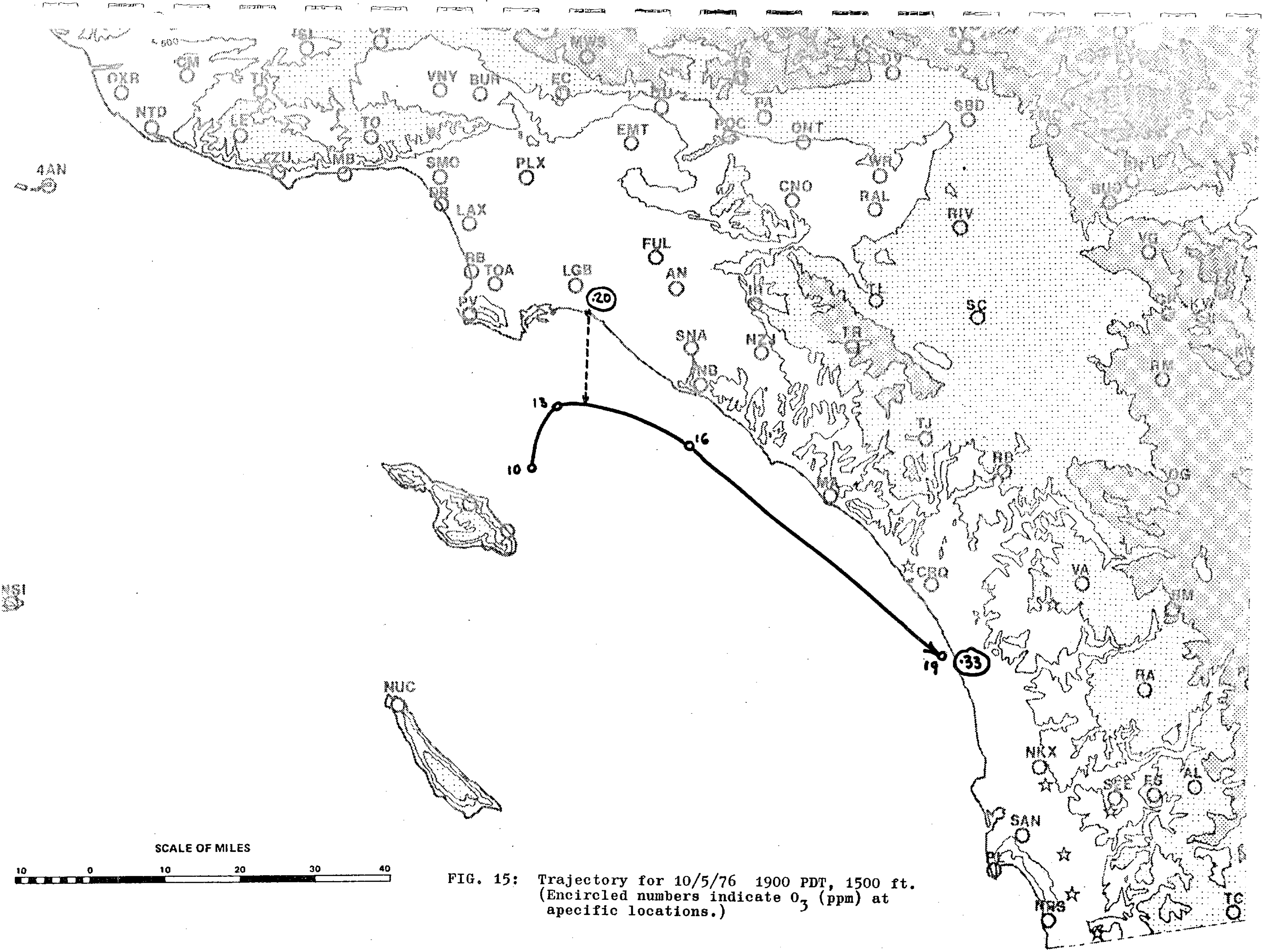

FIG. 15: Trajectory for 10/5/76 1900 PDT, 1500 ft. (Encircled numbers indicate O_3 (ppm) at apecific locations.)

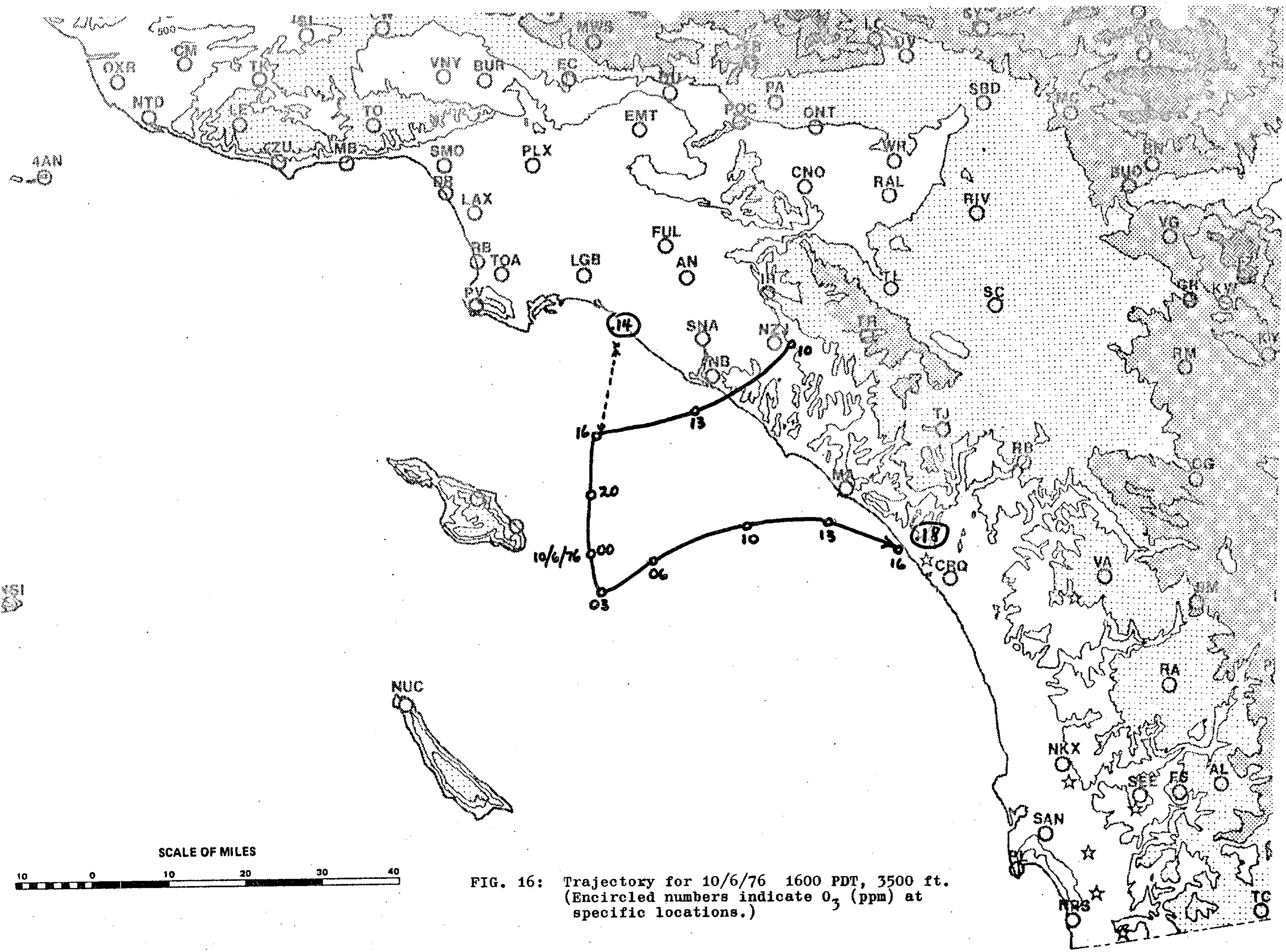

FIG. 16: Trajectory for 10/6/76 1600 PDT, 3500 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

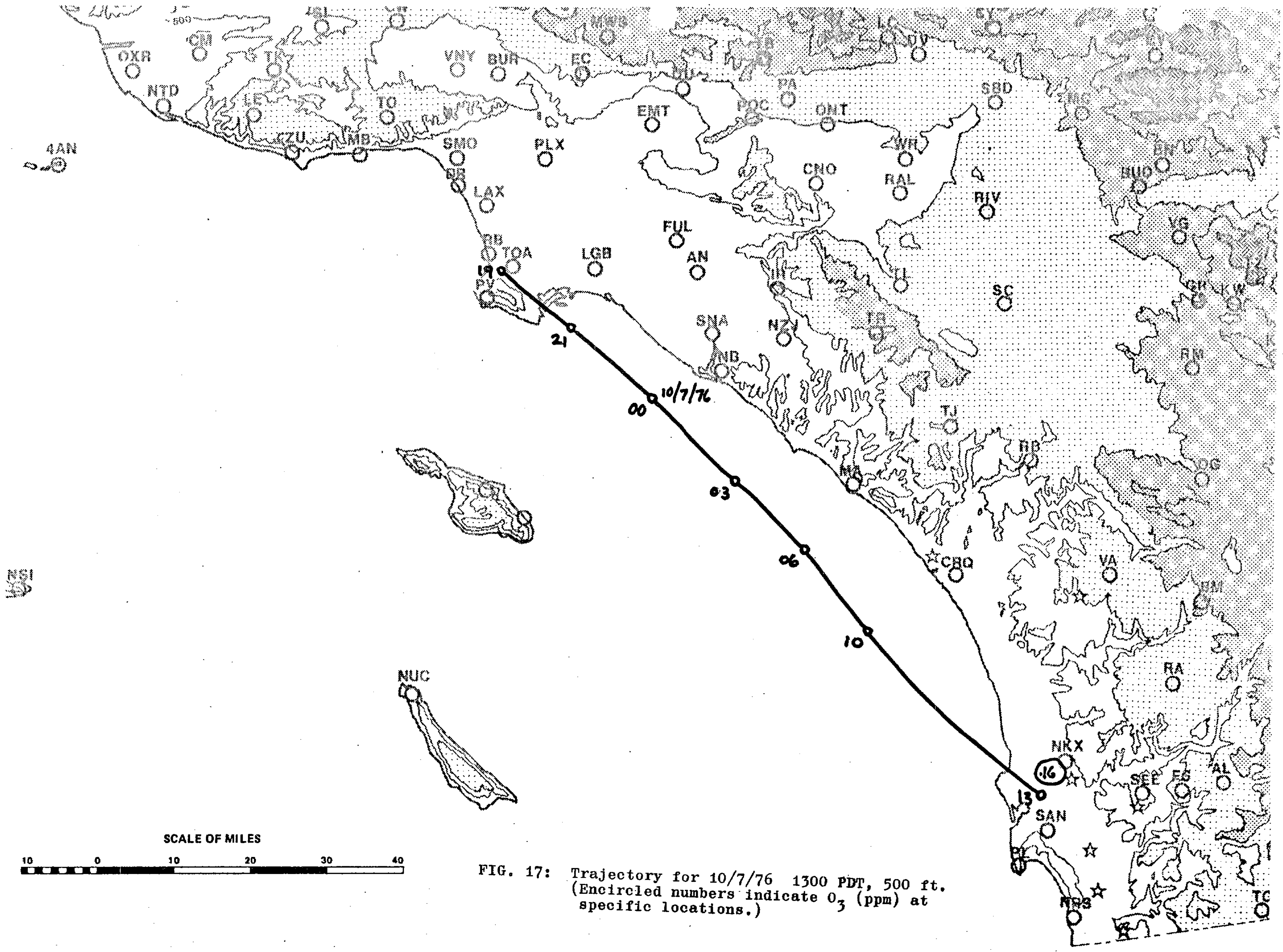

FIG. 17: Trajectory for 10/7/76 1300 PDT, 500 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

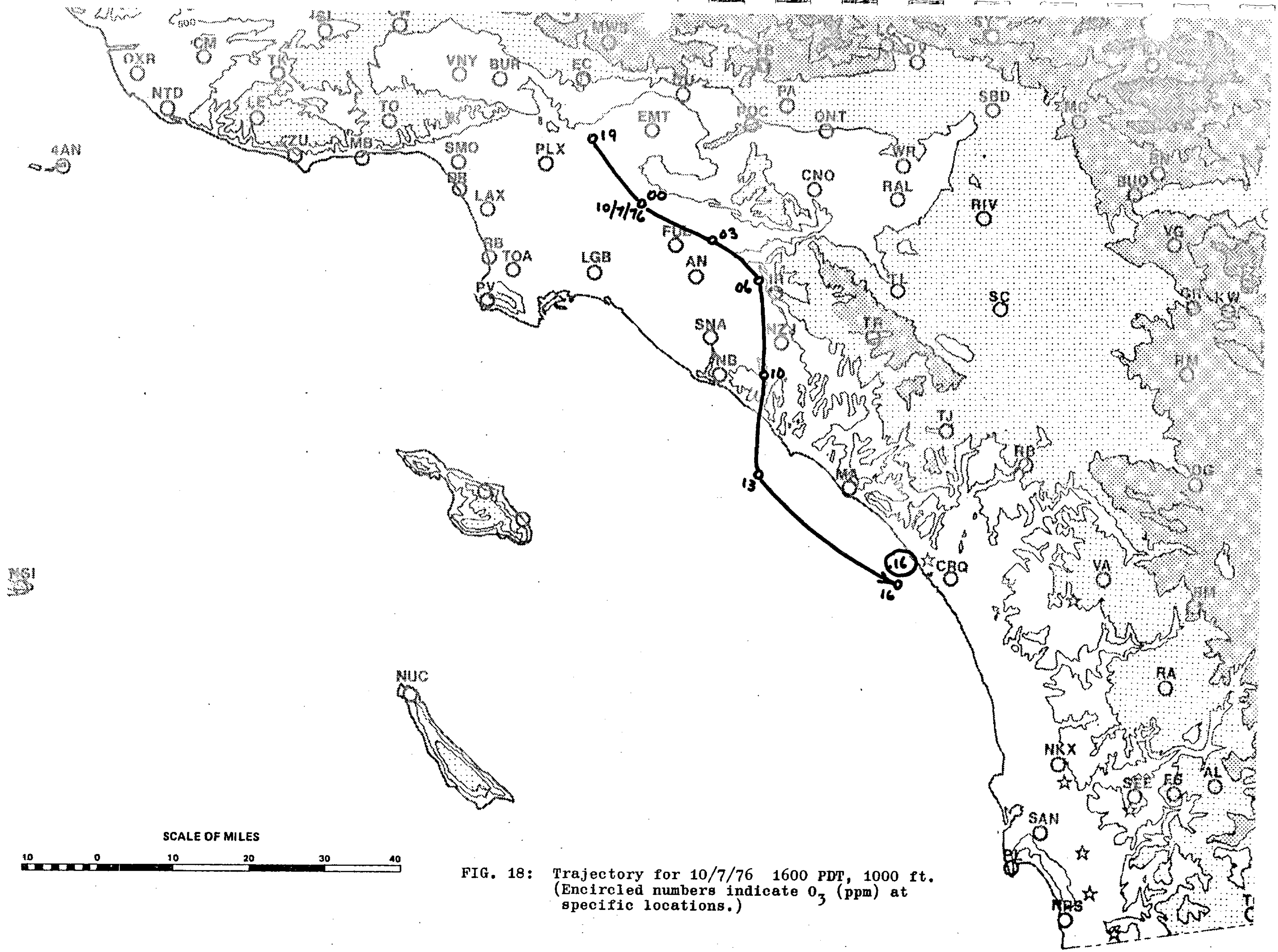

FIG. 18: Trajectory for 10/7/76 1600 PDT, 1000 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

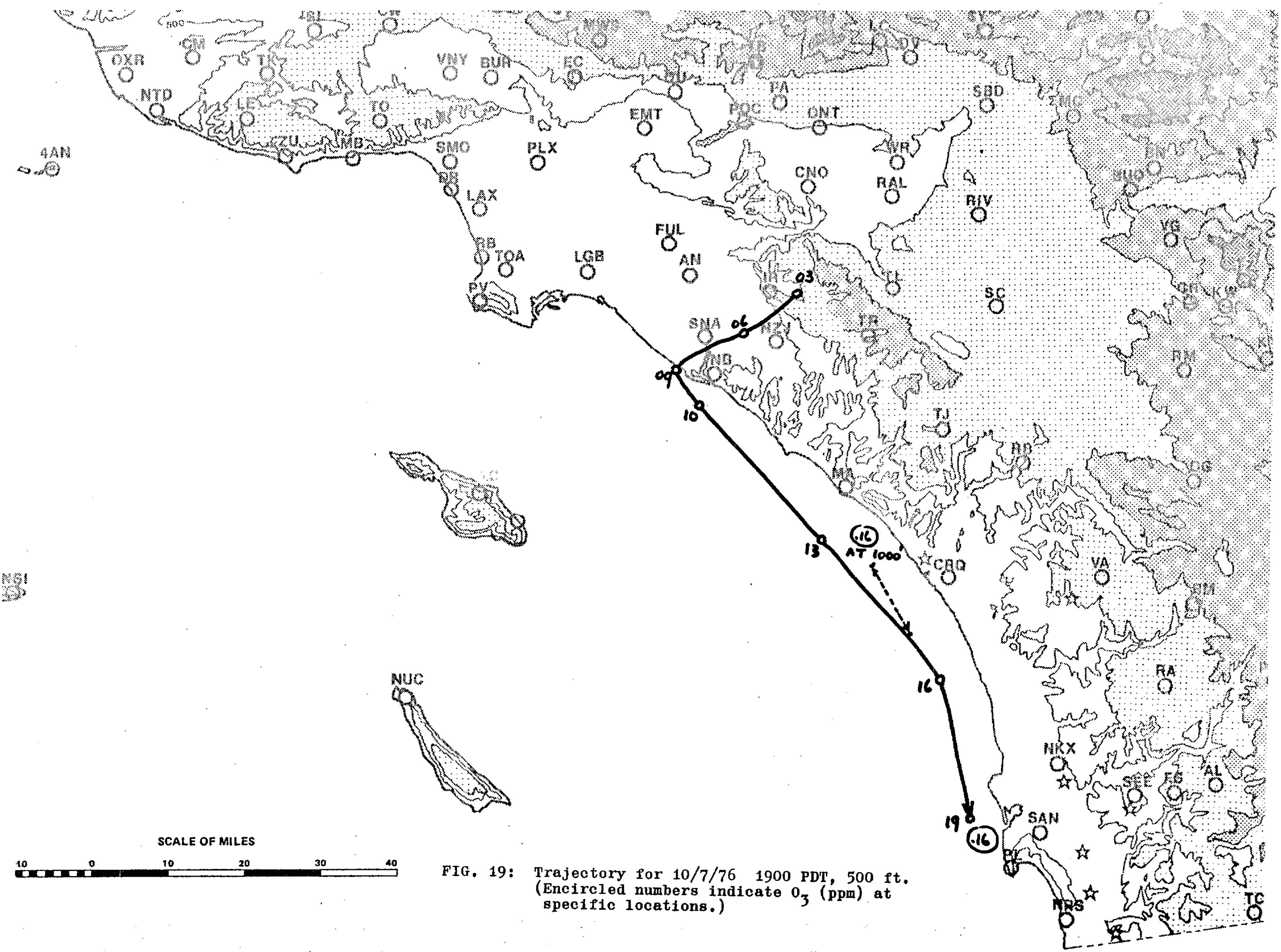

FIG. 19: Trajectory for 10/7/76 1900 PDT, 500 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

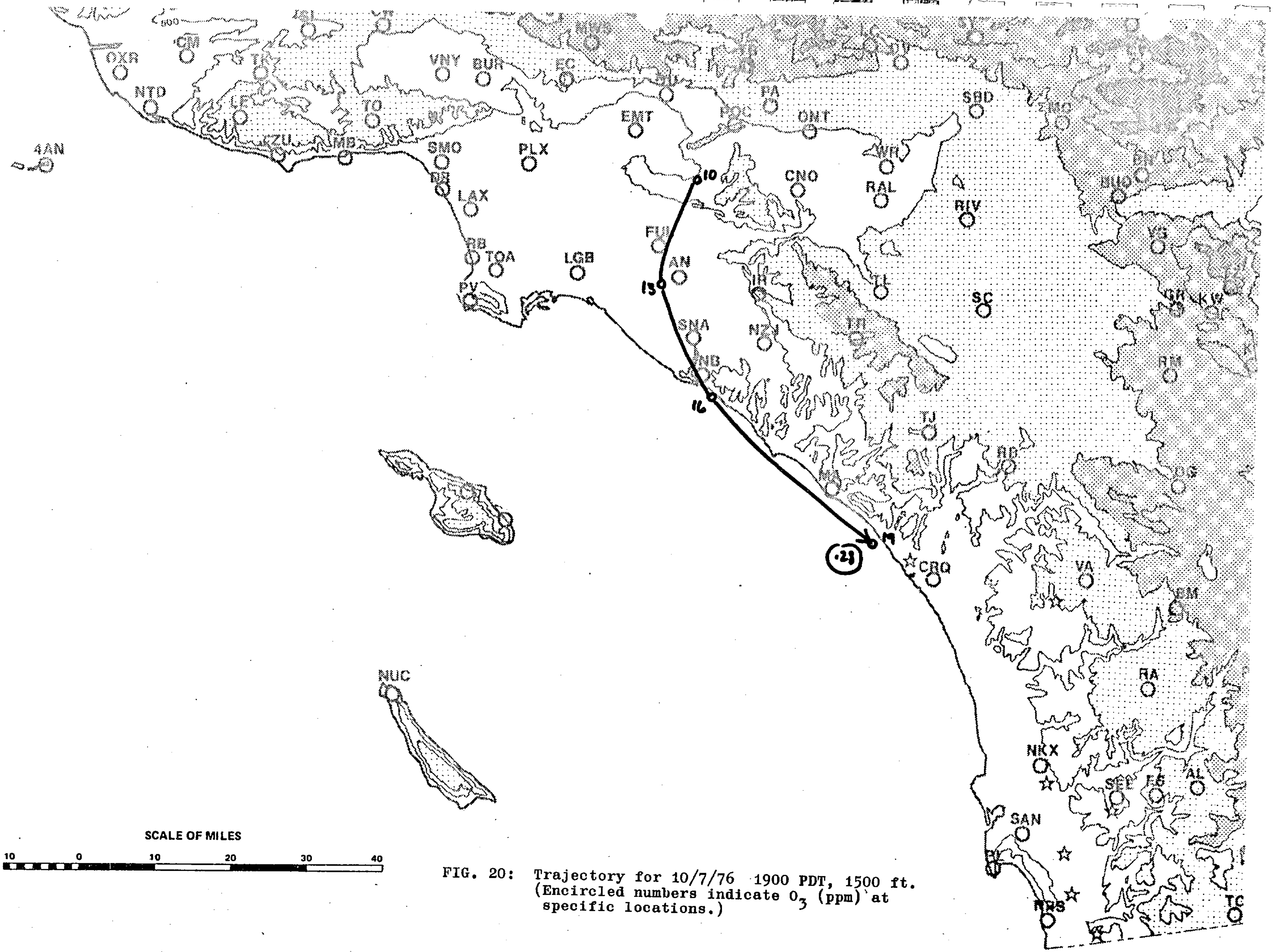

FIG. 20: Trajectory for 10/7/76 1900 PDT, 1500 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

during the hours and days prior to its arrival over the northern San Diego coastline at 1500 PDT, (Fig.21). While this trajectory indicates an ultimate origin in the SCAB, it must be pointed out that the trajectory technique becomes progressively less accurate with time, and in the area off-shore where the trajectory indicates much time was spent by the air parcel in question, the wind data available may be considered as sparse.

On October 12, 1976, however, the trajectory indicates a much more defined path from the SCAB to northern San Diego County. (Fig. 22). It was on this day, too, that the ozone instrument at Black Jack Camp, Catalina Island, received its maximum concentration during the project period. Figure 23 shows the trajectory associated with this occurrence. Its relationship to the trajectory previously discussed, (Fig. 22) is apparent. A general outflow aloft from the SCAB occurred near 10 a.m. which was detected both on Catalina and aloft over the northern San Diego County coast during the mid-afternoon hours.

By mid-afternoon, the distribution of ozone aloft between Long Beach and San Diego was as indicated in the cross-section shown in Figure 24. This is generally typical of the conditions encountered during the "marine layer" cases, with a maximum ozone layer aloft existing just above the inversion base, and northwesterly winds blowing at all locations in the cross-sections.

On October 13, 1976, the maximum ozone aloft was detected at Dana Point during the morning flight. The trajectory associated with this occurrence is shown in Figure 25, which indicates a SCAB origin.

The trajectory for October 14, 1976 is shown in Figure 26. Here the conditions are such that no statement

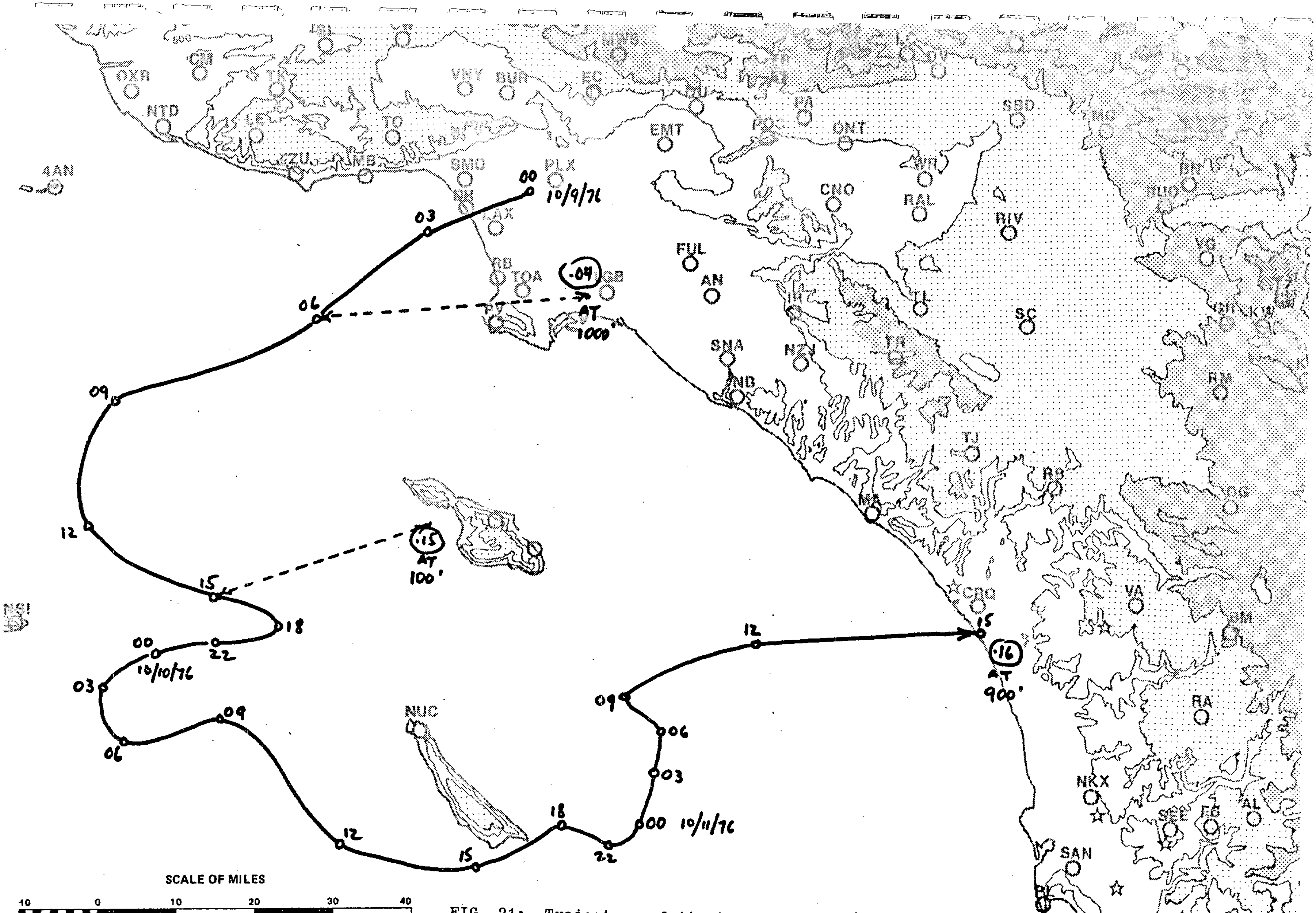

FIG. 21: Trajectory of Air Arriving on 10/11/76 1500 PDT based on winds at: 1000 ft. on 10/11/76, 500 ft. on 10/10, Surface on 10/9

(Encircled numbers indicate O_3 (ppm) at specific locations.)

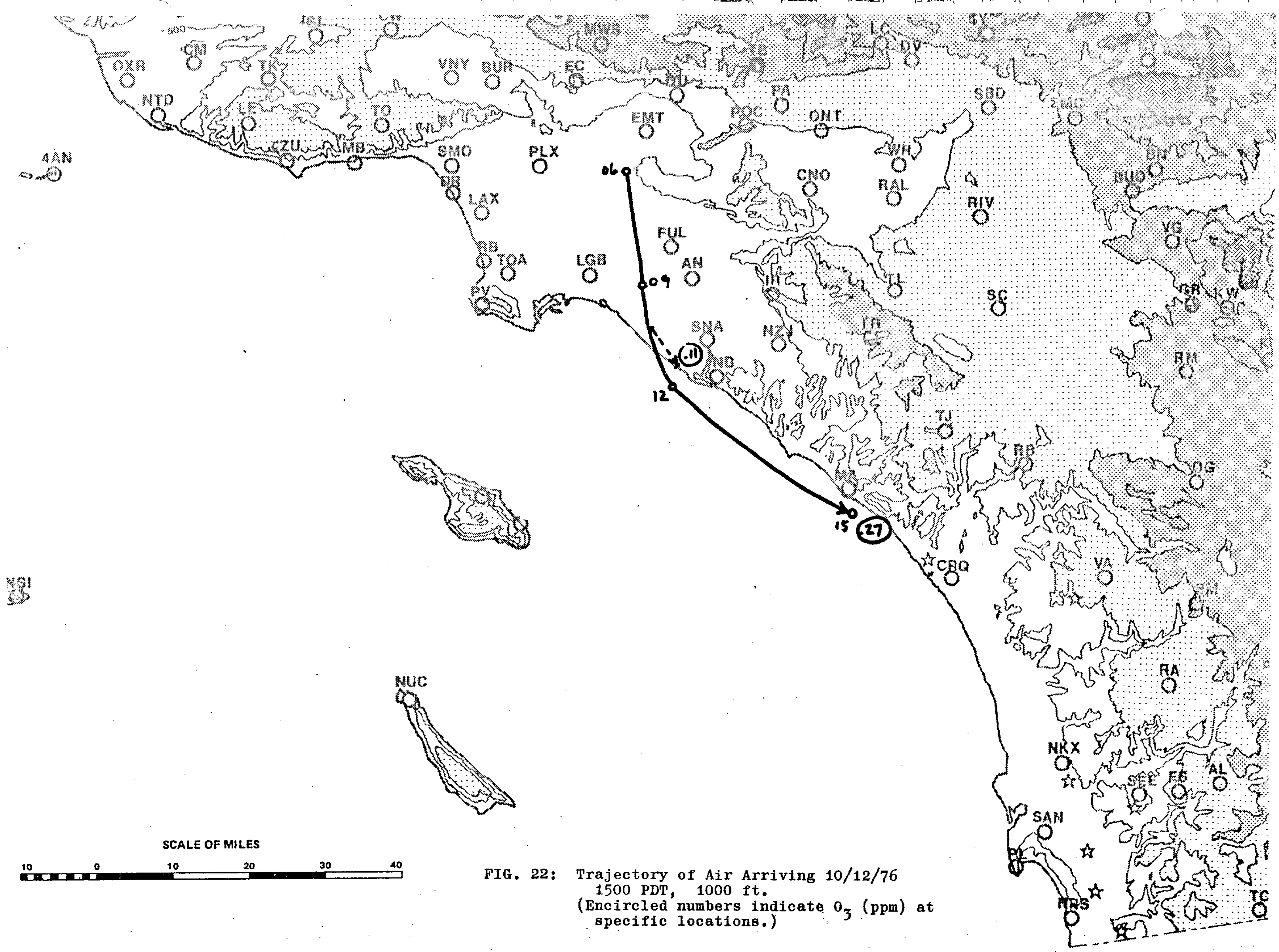

FIG. 22: Trajectory of Air Arriving 10/12/76
1500 PDT, 1000 ft.
(Encircled numbers indicate O_3 (ppm) at specific locations.)

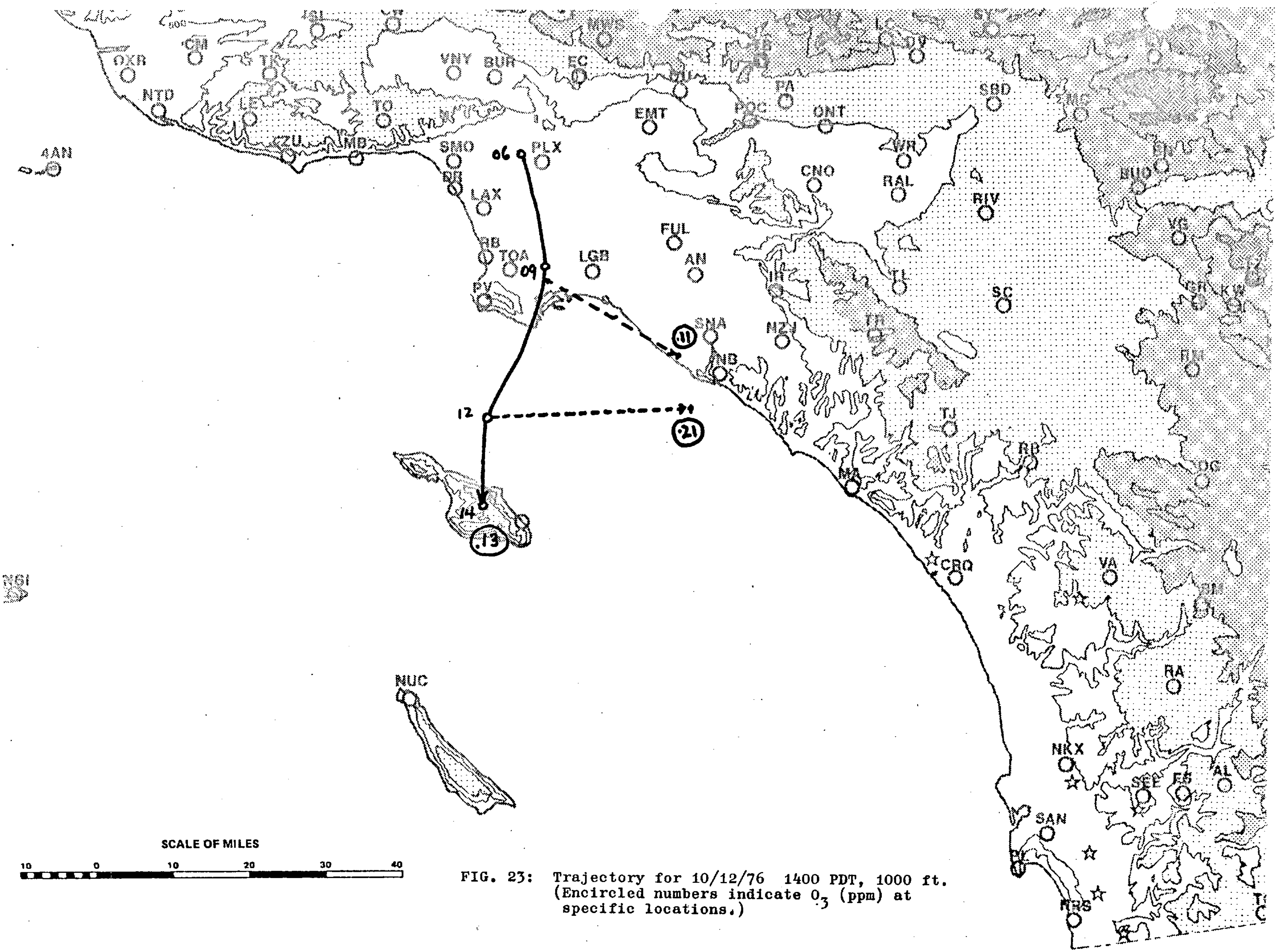

FIG. 23: Trajectory for 10/12/76 1400 PDT, 1000 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

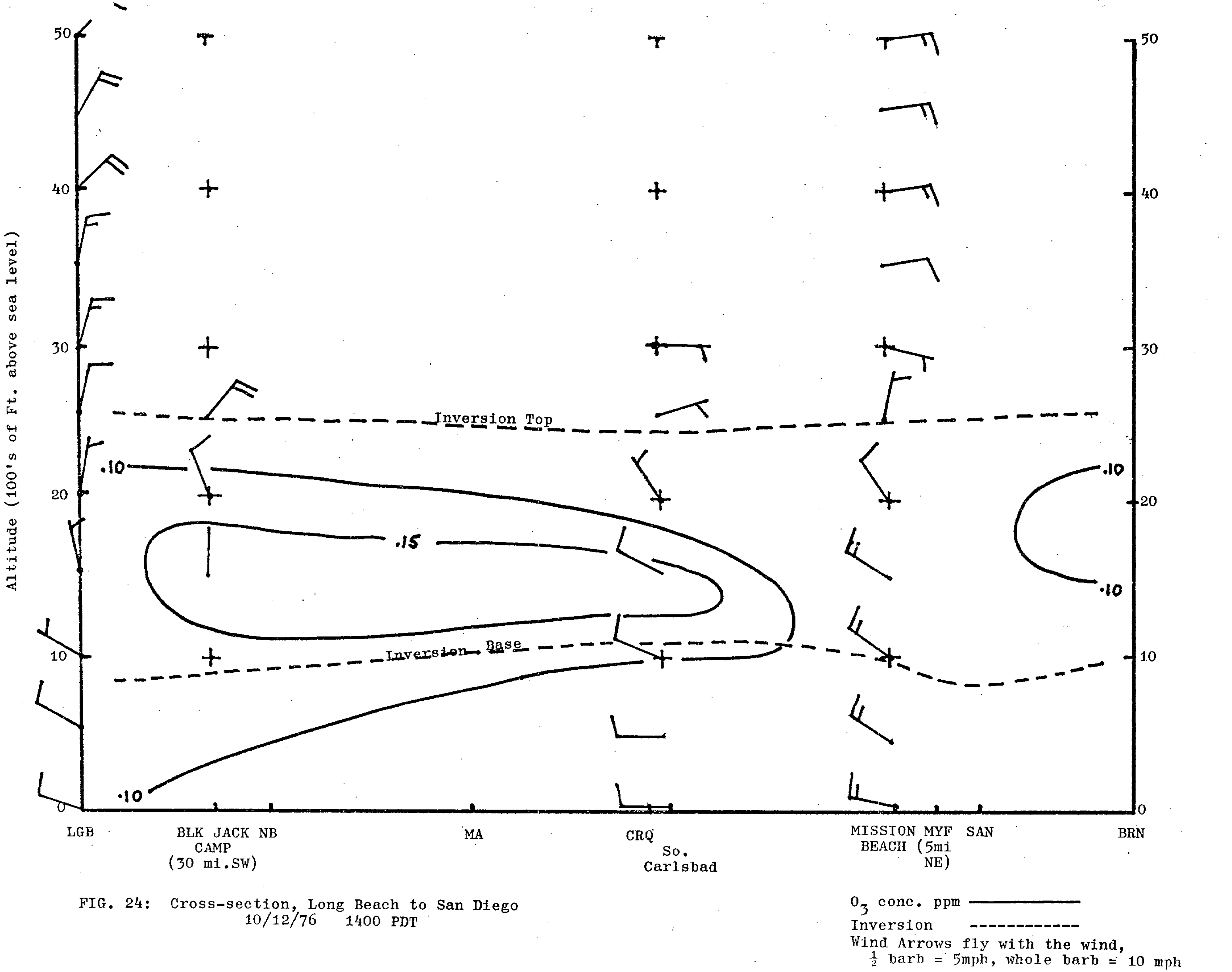

FIG. 24: Cross-section, Long Beach to San Diego
10/12/76 1400 PDT

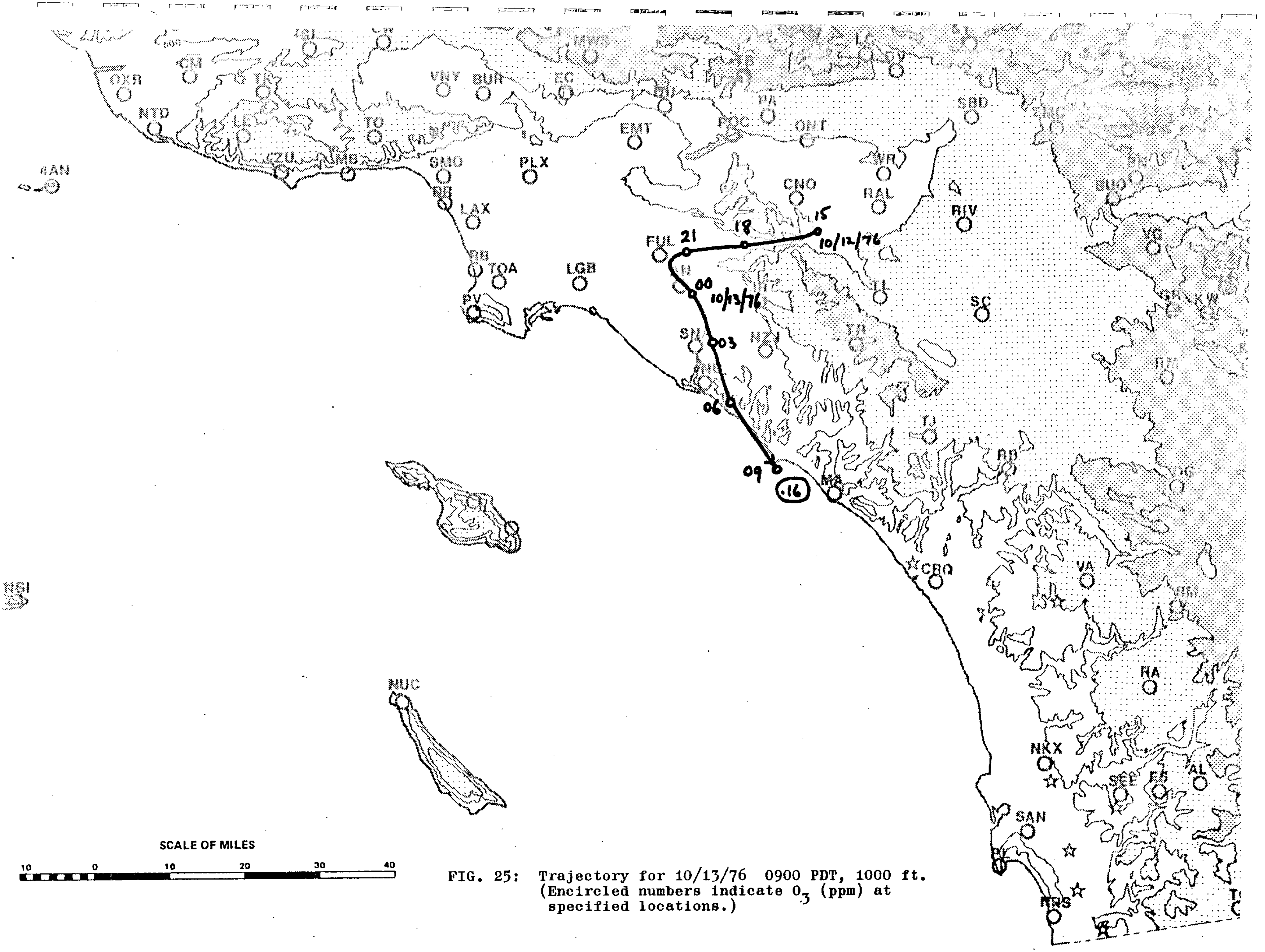

FIG. 25: Trajectory for 10/13/76 0900 PDT, 1000 ft. (Encircled numbers indicate O_3 (ppm) at specified locations.)

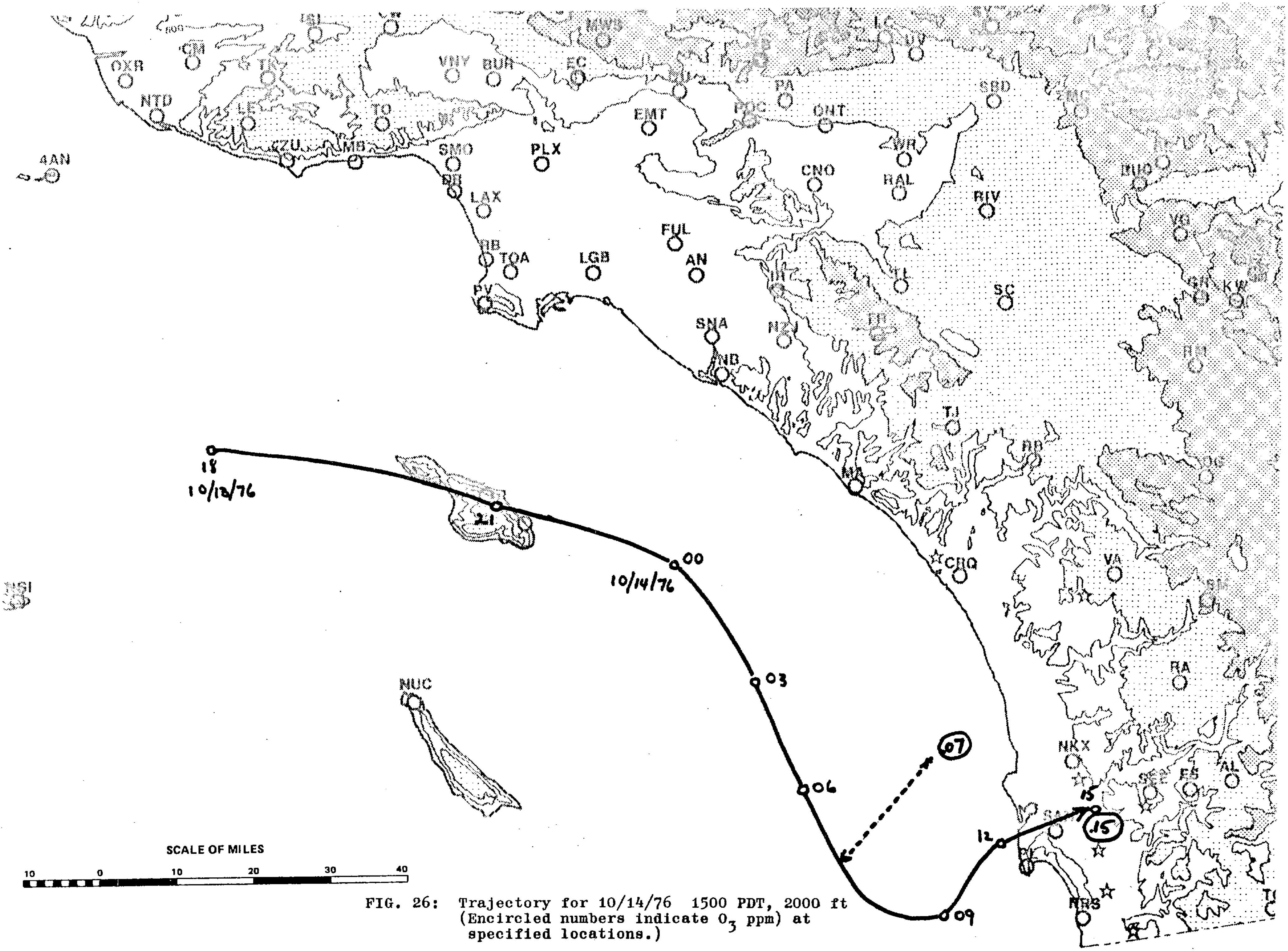

FIG. 26: Trajectory for 10/14/76 1500 PDT, 2000 ft (Encircled numbers indicate O_3 ppm) at specified locations.)

regarding the origin of the maximum ozone aloft found over the inland portion of San Diego can be made. From the trajectory it appears that the air parcel containing the ozone maximum had no path over populated areas during its history immediately prior to its arrival at San Diego.

In summary, for the marine layer cases (October 5-7, 11-14, 1976) the trajectory construction process indicates the following:

a.	Maximum O_3 in San Diego County, apparent source in SCAB:	7 cases,	on 3 days
b.	Maximum O_3 in San Diego County, apparent source indeterminate:	2 cases,	on 2 days
c.	Maximum O_3 in So. Orange County, apparent source in SCAB:	1 case,	on 1 day
	Total	10 cases	6 days

VII OTHER ANALYSES

A. Estimation of Background Ozone Levels

The extensive mapping of the ozone concentrations over the Southern California area by use of the instrumented aircraft provided many data points, both in obviously polluted air and within clear air well above the mixed layer. The ozone concentrations encountered clearly indicate that "clean" air in Southern California, during the study period at least, has a background ozone value of about 0.04 ppm.

There were instances of ozone concentrations registering zero or near zero levels. However, these were always at low altitude, and appeared to be associated with large point sources such as power plants and refineries, which release quantities of NO, a gas known to "use up" ozone as it reacts to form NO_2.

B. Primary Pollutant - Ozone Relationships

The analysis of the bag samples obtained by the aircraft during the San Diego portions of the flights, (generally off-shore from La Jolla and Carlsbad) together with the measured ozone values, permits a comparison of air quality characteristics of the high-ozone and low-ozone situations. A summary of hydrocarbon and carbon monoxide values for high ($O_3 \geq .15$ ppm) and for very low ($O_3 \leq .01$ ppm) is shown in the following table:

		Ave. (ppm)				
	No.Obs	O_3	THC	CO	THC-CH_4	Ratio THC-CH_4/THC
High O_3 Cases:	8	.19	4.24	1.15	1.83	.411
Low O_3 Cases:	3	.01	4.10	.90	2.23	.512

The last column, giving the ratios of total to non-methane hydrocarbons represents the average of ratios taken for each individual occurrence; it is not the ratio of the average total hydrocarbon to the average non-methane hydrocarbons.

Inspection of the data for these high and low ozone cases indicates that all the low ozone occurrences were found off La Jolla during the 0700 - 0800 PDT period. The high ozone cases all were found during the afternoon flights either at the La Jolla or Carlsbad sampling stations.

It is apparent that the values for hydrocarbons and carbon monoxide do not differ significantly for these extreme cases. Only in terms of the ratio of reactive to total hydrocarbons does an apparent difference exist. The high ozone cases have about 20% less reactive hydrocarbons to total hydrocarbons than the low-ozone cases. This is as expected, since more of the reactive hydrocarbons are used up in photochemical reactions which result in ozone formation, although the amount of data is statistically insufficient to call this difference significant.

The values of total hydrocarbons and carbon monoxide are at concentrations generally similar to that recorded at the surface by the Oceanside air monitoring station, during periods when air is moving over the station from the sea.

While the CO values reported are low in comparison with central city air samples, the total hydrocarbons appear to be about equal to values reported in other areas of Southern California.

What this means in the context of an assumed aging photochemical pollution cloud moving down the coast toward San Diego is not clear. One would expect that the hydrocarbon concentration, given both diffusion and photochemical reactions, would be relatively decreased, compared with the CO, which supposedly is affected only by diffusion.

C. Comparison of Trajectories Derived from Surface and Upper Air Data

The ozone maxima as recorded at ground-level stations operated by the San Diego Air Pollution Control District were used as the trajectory ending points of the parcels that had their previous trajectories deduced in two ways: from surface wind data maps, and from upper level winds.

In the case of three of the sampling days, those associated with the "Santa Ana" wind conditions, the altitude of the ozone aloft was so near the surface that only surface winds were needed in determining trajectories. The other 7 days were subjected to trajectory analysis using the two sets of data. The upper winds were chosen according to the altitude of the ozone maximum, as measured by the aircraft. Results of these analyses in terms of trajectory origin as shown in Figures 27-32, can be summarized in the table below:

Date	Sta.	Time (PST)	Max O_3 (ppm)	Origin of Trajectories Using Sfc. Winds	Origin of Trajectories Using Upper Winds
10/5/76	BRN	12	.18	Unknown (too few data)	
10/6	BRN	13	.14	Offshore San Diego	SCAB
10/7	BRN	13	.14	Catalina Channel	SCAB
10/11	ALP	13	.12	San Diego	San Diego Off-shore
10/12	OCN	19	.12	Offshore Oceanside	SCAB
10/13	BRN	13	.13	Offshore San Diego	SCAB
10/14	ALP	13	.15	Offshore San Diego	SCAB (48 hr (earlier)

From the table above it appears that the upper flow is such that parcels containing ozone maxima can be traced back to the Los Angeles Basin on many days on which surface wind data would indicate a San Diego source region. In the sample of days reported on here, only one day had both kinds of trajectories indicating a San Diego origin.

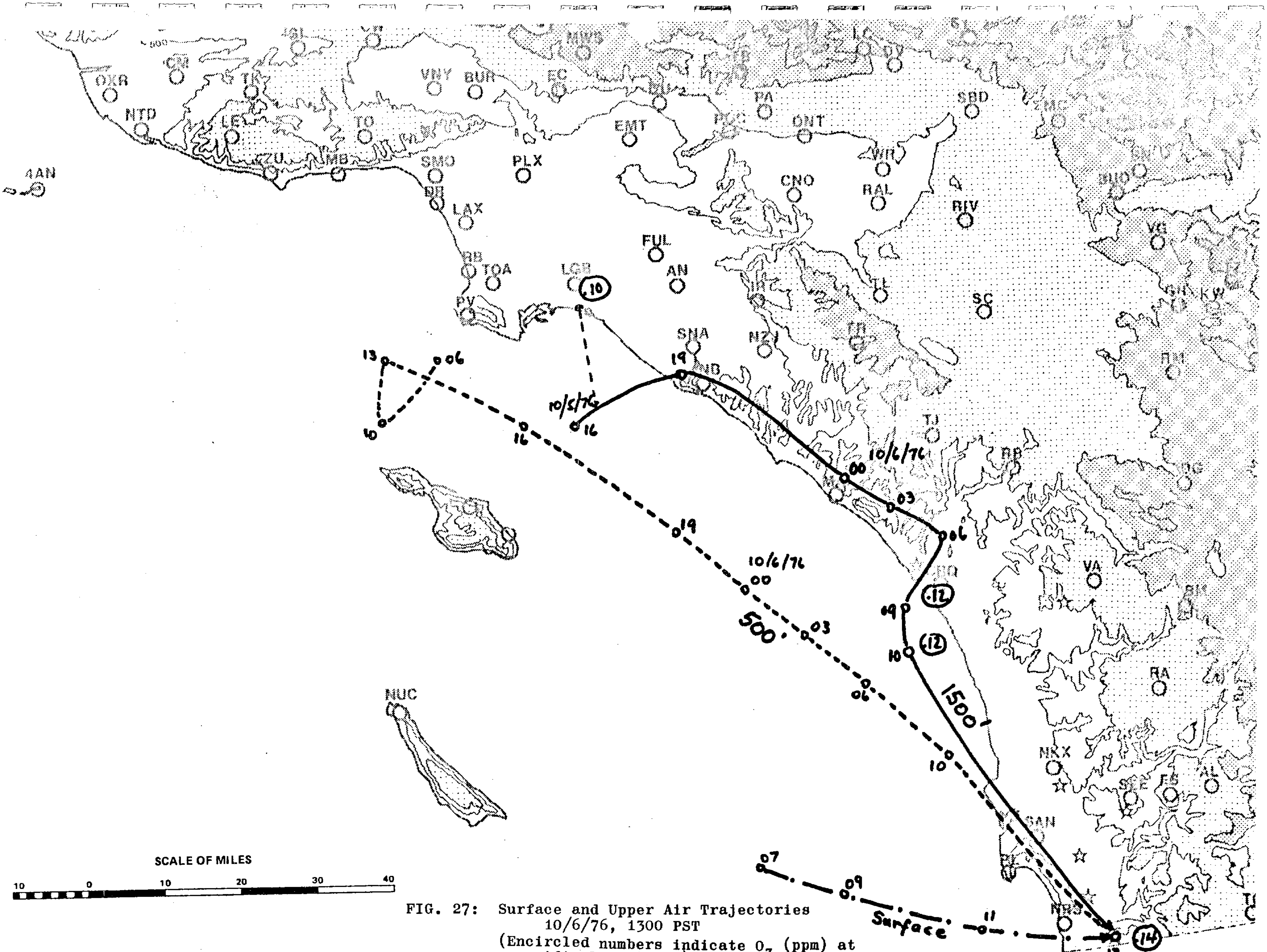

FIG. 27: Surface and Upper Air Trajectories
10/6/76, 1300 PST
(Encircled numbers indicate O_3 (ppm) at specific locations.)

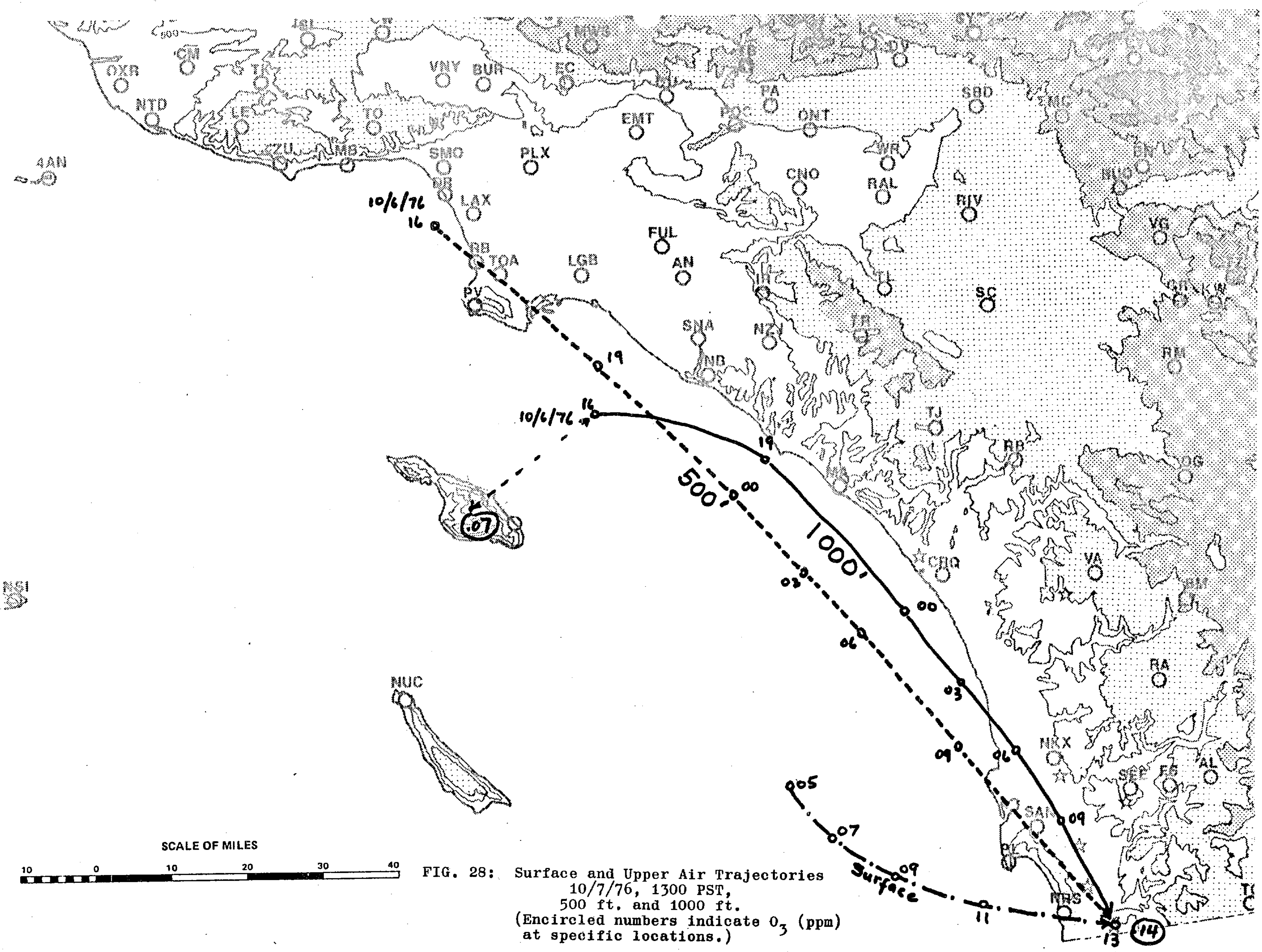

FIG. 28: Surface and Upper Air Trajectories 10/7/76, 1300 PST, 500 ft. and 1000 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

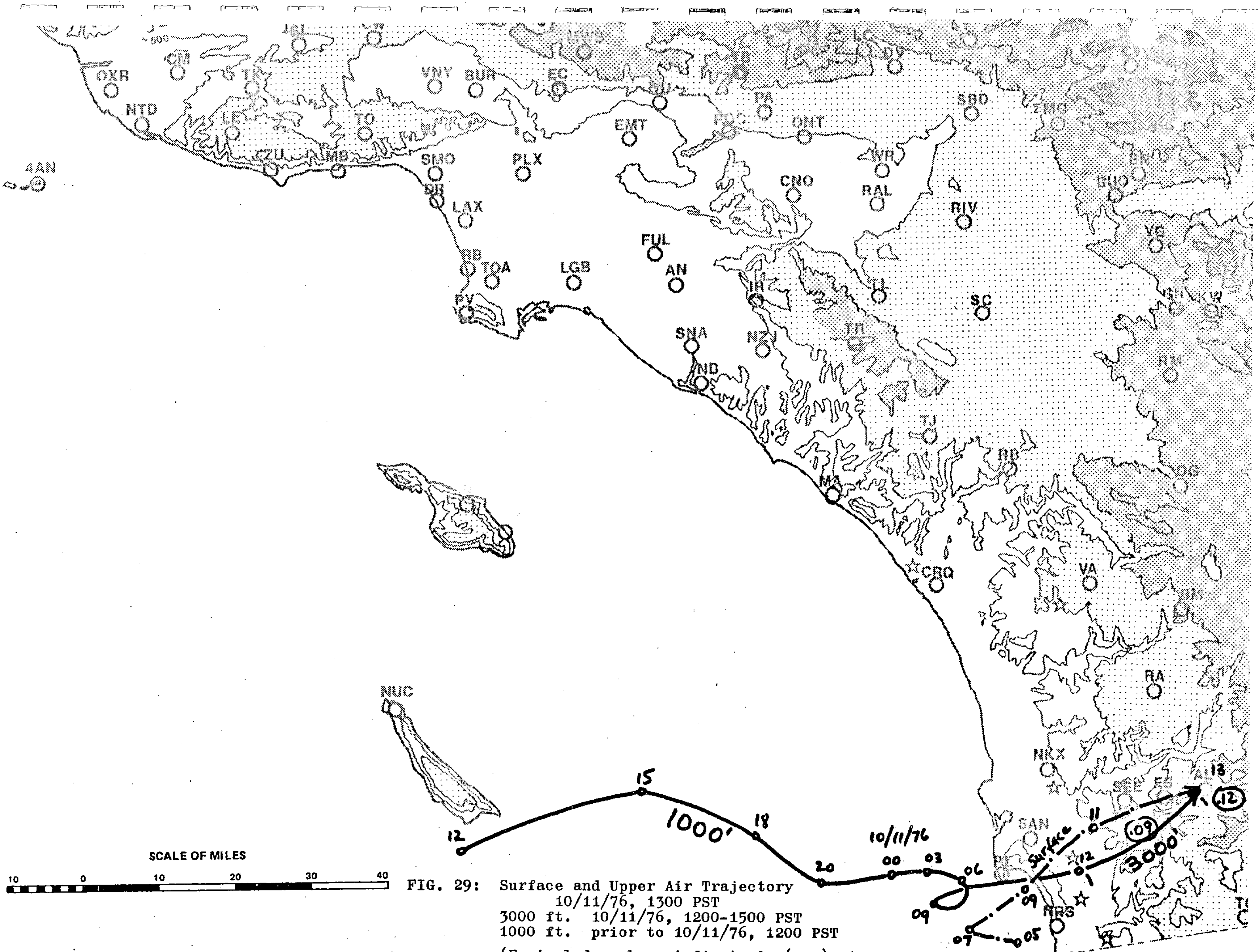

FIG. 29: Surface and Upper Air Trajectory
10/11/76, 1300 PST
3000 ft. 10/11/76, 1200-1500 PST
1000 ft. prior to 10/11/76, 1200 PST
(Encircled numbers indicate O_3 (ppm) at specific locations.)

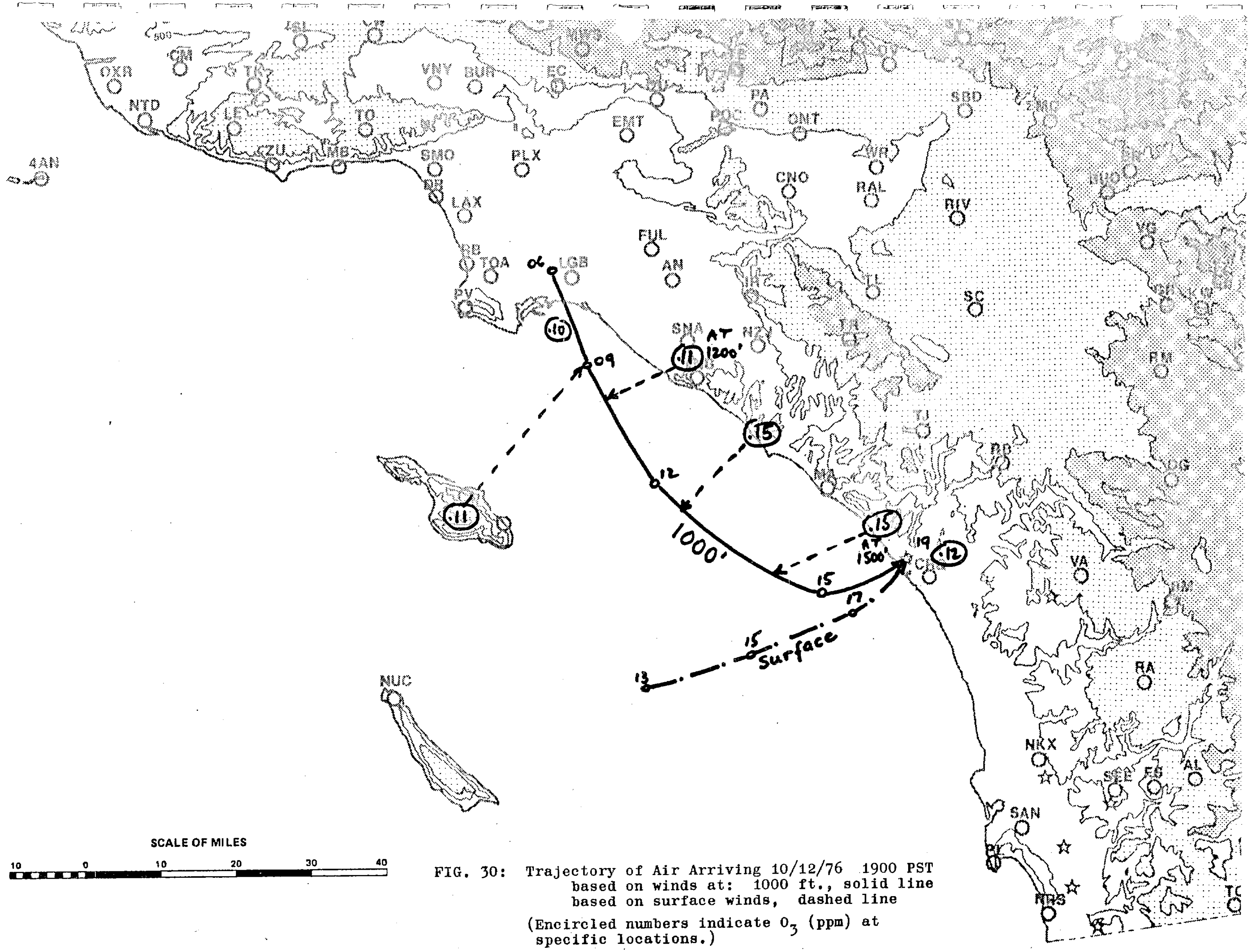

FIG. 30: Trajectory of Air Arriving 10/12/76 1900 PST based on winds at: 1000 ft., solid line based on surface winds, dashed line

(Encircled numbers indicate O_3 (ppm) at specific locations.)

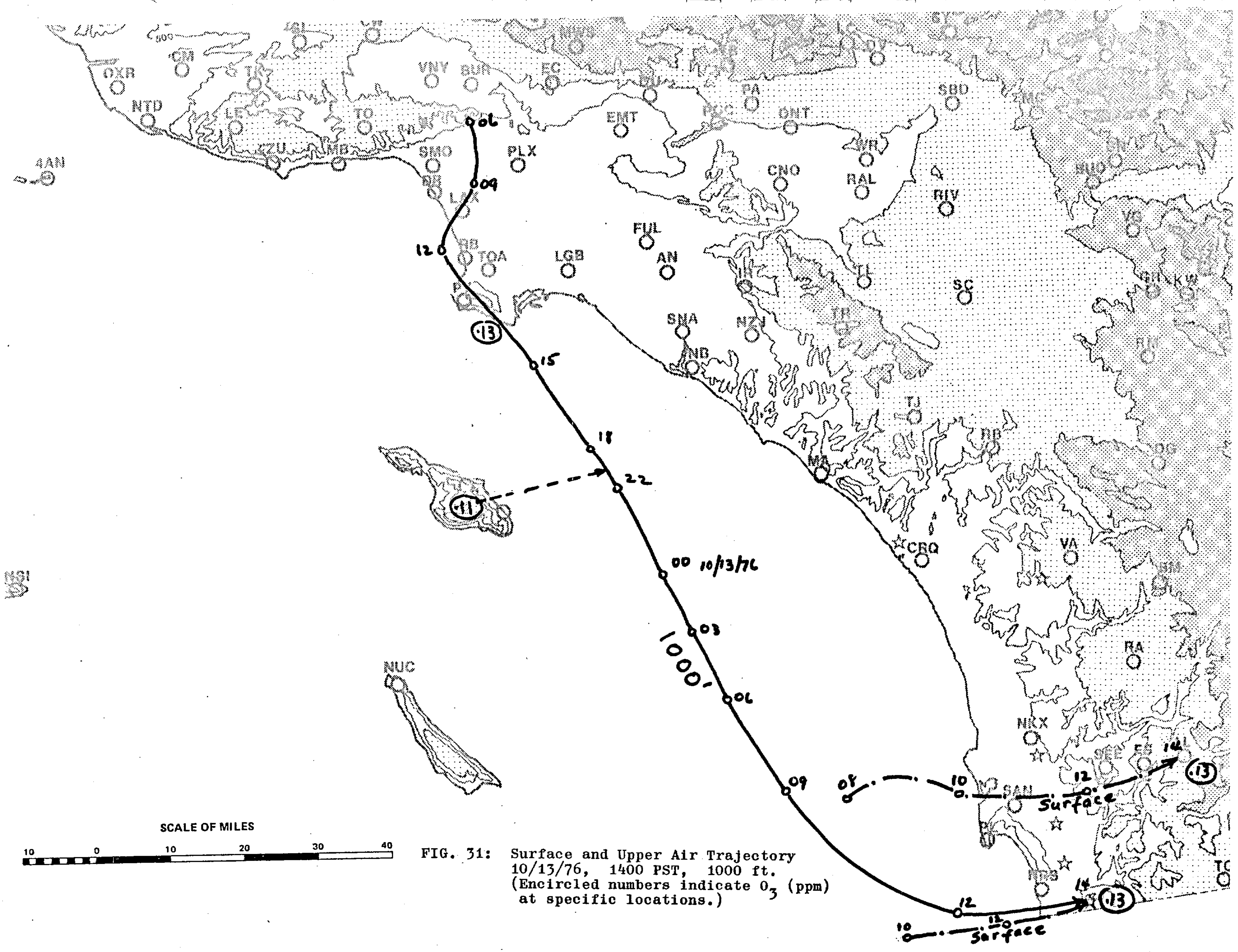

FIG. 31: Surface and Upper Air Trajectory 10/13/76, 1400 PST, 1000 ft. (Encircled numbers indicate O_3 (ppm) at specific locations.)

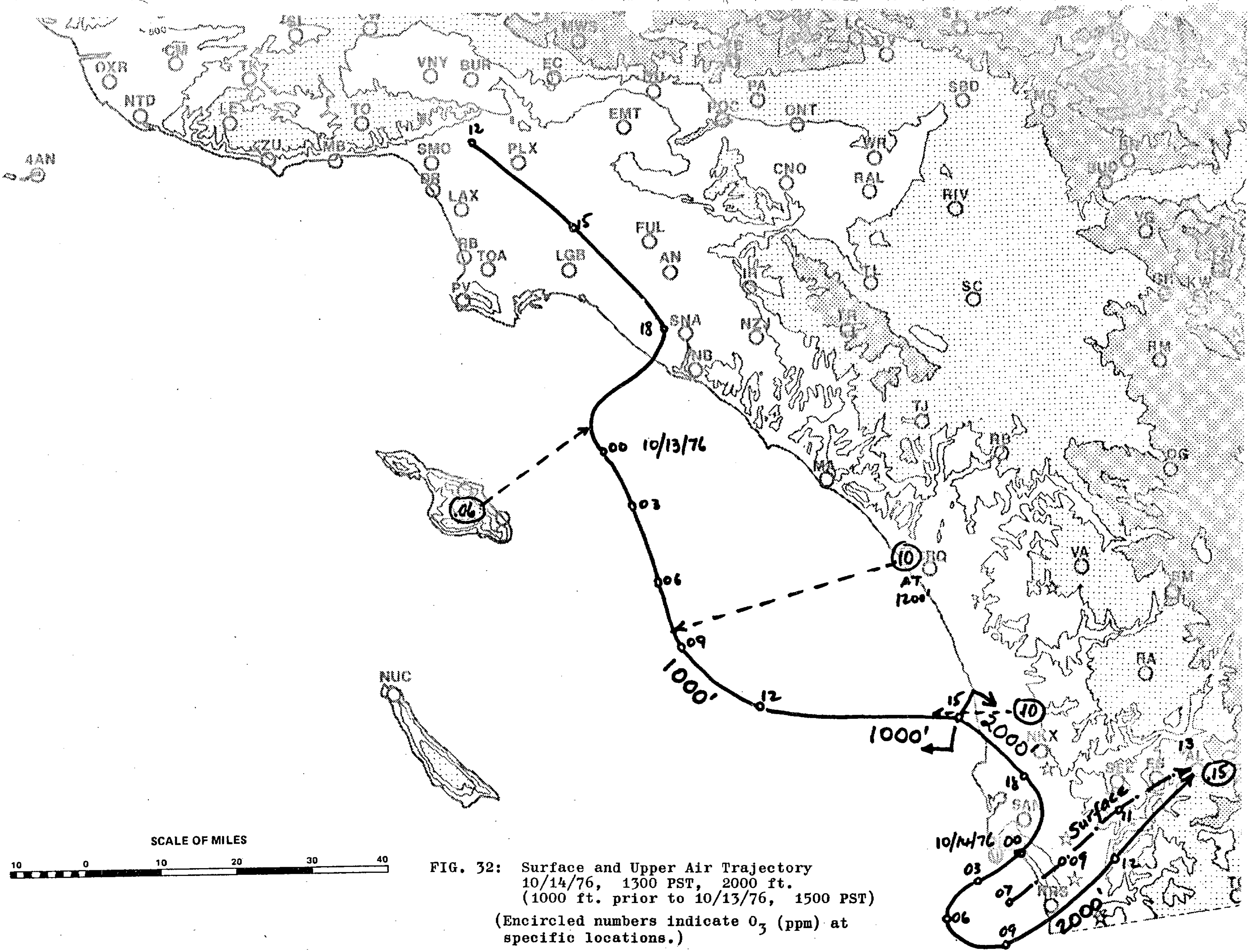

FIG. 32: Surface and Upper Air Trajectory
10/14/76, 1300 PST, 2000 ft.
(1000 ft. prior to 10/13/76, 1500 PST)

(Encircled numbers indicate O_3 (ppm) at specific locations.)

Inspection of the trajectories based on surface wind data in the San Diego area reveals an interesting fact - namely, the trajectories of surface parcels containing ozone maxima all seem to be out over the ocean well off shore during the San Diego morning traffic rush hours.

In determining then, where the primary pollutants emitted at this time go, it would appear as though the effect of the San Diego source may well not be measured by the San Diego County sampling network. The morning traffic emissions very likely are carried southward along shore, to impact on coastal areas of northern Baja California. While no trajectories have been constructed to verify this proposition, it is based on assumption of a similarity in flow conditions over the greater San Diego area, including the adjacent coastal portions of Mexico.

D. Time Cross-sections Along a Trajectory

Conditions on October 6, 1976 were measured between Long Beach and San Diego with sufficient frequency so that the characteristic ozone layer aloft could be picked up at various points in time along the trajectory.

Figure 33 presents a series of soundings showing the ozone layer aloft (above the inversion base). The selection of sounding data was based on the trajectory for an air parcel arriving at 1500 ft (450 m) over Brown Field at the time of ozone maximum there. This trajectory is given in Figure 27. Also shown is the trajectory of air derived from surface wind reports, and from the 500 ft winds. The 1500 ft (450 m) trajectory is affected by the northwesterly flow found aloft and thus indicates an origin in the South Coast Air Basin, while the surface trajectory, limited by lack of off-shore data, has the parcel

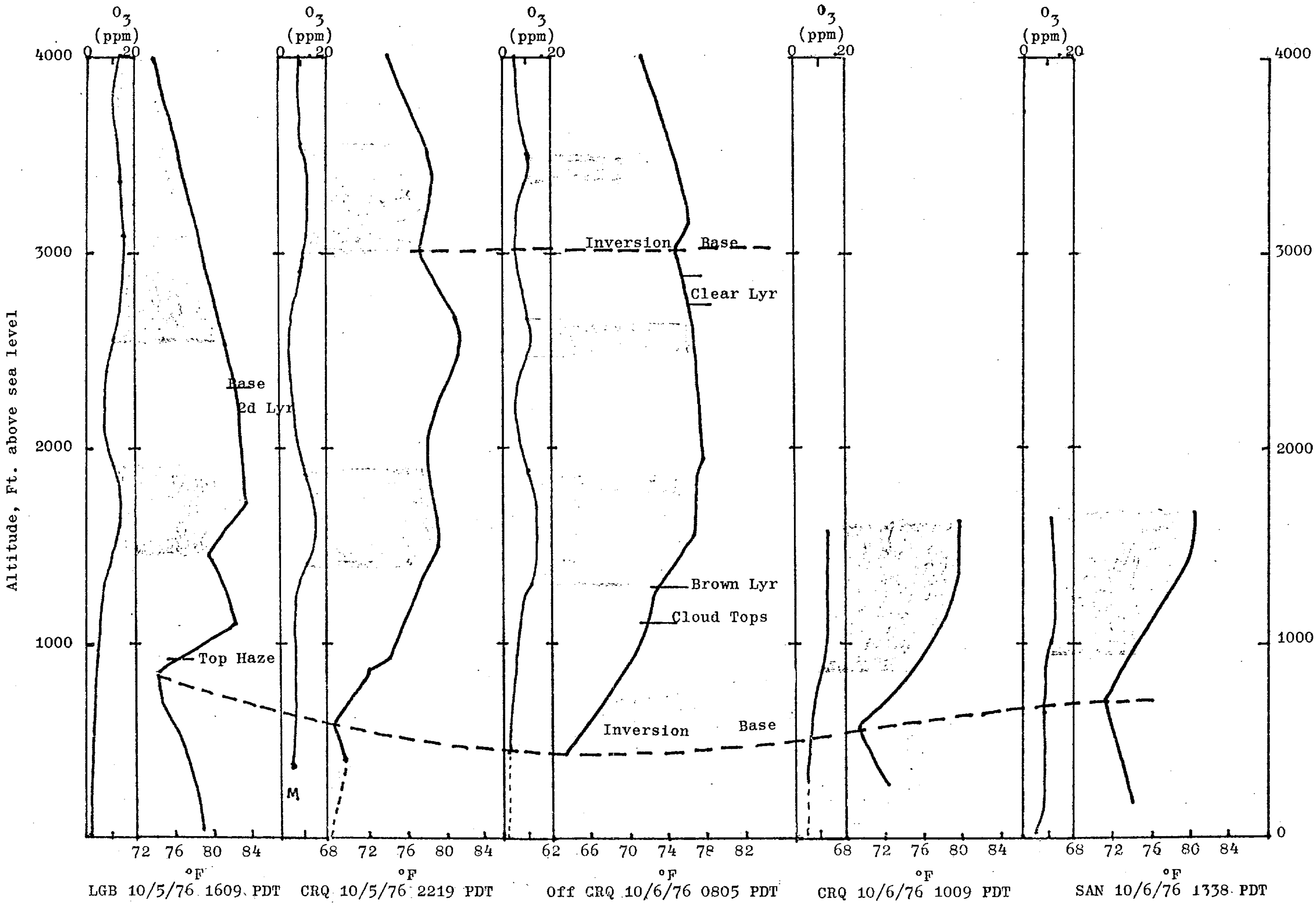

FIG. 33: Soundings of temperature and O_3, taken along trajectory track associated with O_3 maximum at San Diego, 10/6/76.

(O_3 conc. of 0.10 ppm indicated by shading.)

located between San Diego and San Clemente Island during the early morning (high traffic source) hours.

The various soundings in Figure 33 show the lowering of the inversion with time from October 5th through the morning hours of October 6th. The ozone layer aloft also shows this trend. By mid-day on October 6th the heating of the ground causes an increase in the depth of the mixed layer, so that the ozone aloft is tapped and mixed to the surface. On the sounding for San Diego at 1338 PDT October 6, 1976, are indicated estimated temperatures of 76° and 78°F, the approximate temperature occurring at Brown Field during the time of ozone maximum there. These indicate that the material aloft could be brought down to produce the recorded maximum of 0.14 ppm.

The question of how much of the ozone at the surface is due to the ozone cloud aloft and how much is due to the aging of a locally-produced photochemical cloud below the inversion is difficult to answer quantitatively. In the October 6, 1976 case, however, the trajectories (both those from surface winds and those from the winds aloft) indicate that the air mass giving the high ozone values at Brown Field did not move over the central San Diego traffic area at the time of the morning traffic rush. Indeed, the surface wind derived trajectory indicates no passage over an urbanized area at all. This fact, together with the established presence of an ozone layer aloft makes it appear that at least some of the ozone maxima occurring in the San Diego area under non-"Santa Ana" conditions may be due to transport of an aged cloud aloft with the subsequent fumigation of the ozone to the surface.

Whether the fumigation process can account for the surface ozone concentrations is certainly questionable - one would expect lower surface readings when the ozone cloud aloft is mixed down to the surface, instead of the observed fact that, in coastal areas of San Diego, the surface and aloft ozone maxima are about the same.

Another look at the aircraft ozone data provides an insight to a possible alternate explanation. It was noted that the ozone maxima aloft were underlain by relatively low ozone values in the mixed layer. At mid-day and later, the mixed layer generally showed a constant level of ozone up to and including the layer aloft. (See the last panel in Figure 33).

Perhaps what is involved here is the effect of differential aging in the air mass, with the air above the coastal stratus cloud responding to unrestricted ultraviolet radiation and thus forming ozone at a faster rate than the air below or within the coastal cloud deck. With time and the movement of the air inland, the stratus clouds dissipated and finally the air mass in the mixed layer is allowed to reach its ozone-potential.

If it can be assumed that the air mass above the cloud and that within the mixed layer both had common origins, and thus have the same ozone potential, then it follows that the lower mixed layer can achieve the same ozone concentrations as those detected aloft, given enough exposure to the sun's radiation.

To test this theory, the situation of October 6, 1976 was reanalyzed. In addition to the trajectory based on 1500 ft wind, which represents the ozone maximum layer aloft, another trajectory, for the 500 ft wind, was constructed. (See Fig. 27) This represents the mixed layer below the coastal clouds. The 500 foot trajectory leads back to the same general area as does the one using the 1500 ft winds - off-shore the SCAB. (The trajectory could not be carried farther due to the lack of earlier wind data.)

E. Southern California-wide Occurrence of Ozone

As part of the analysis of the data obtained during the October 5-14, 1976 field period, all available ozone data from the various sampling networks in Southern California were plotted and analyzed in terms of geographical variation of concentration and time of occurrence of the maximum.

Each of the 10 days of the field operations were treated by plotting the maximum hourly value for all the surface ozone or oxidant reporting stations. Maps showing isolines of ozone concentrations are given in Appendix K, Volume II.

Some of these maps have been reproduced in a previous section, and show the variation occurring from day to day. (See Section VI). The main impression these maps give is that the basic ozone cloud of Southern California is associated with the South Coast Air Basin. When on-shore flow is pronounced, the ozone maximum is located in the interior reaches of the Los Angeles Basin. On off-shore flow days, the ozone cloud is found along the south coast of the South Coast Air Basin, or over the coastal area of San Diego County.

When the marine layer is relatively deep, the ozone cloud tends to move into the mountain regions to the north of the Los Angeles Basin.

When the timing of the ozone maximum is considered, an interesting pattern emerges - the coastal locations tend to have later ozone maximum than do stations located adjacent to the coast, as seen in Figure 34. This Figure which represents the median time of ozone maximum (for non-"Santa Ana" days) at all the stations, indicates a zone of early ozone maximum that is found some distance inland, extending from West Los Angeles to San Diego. Farther

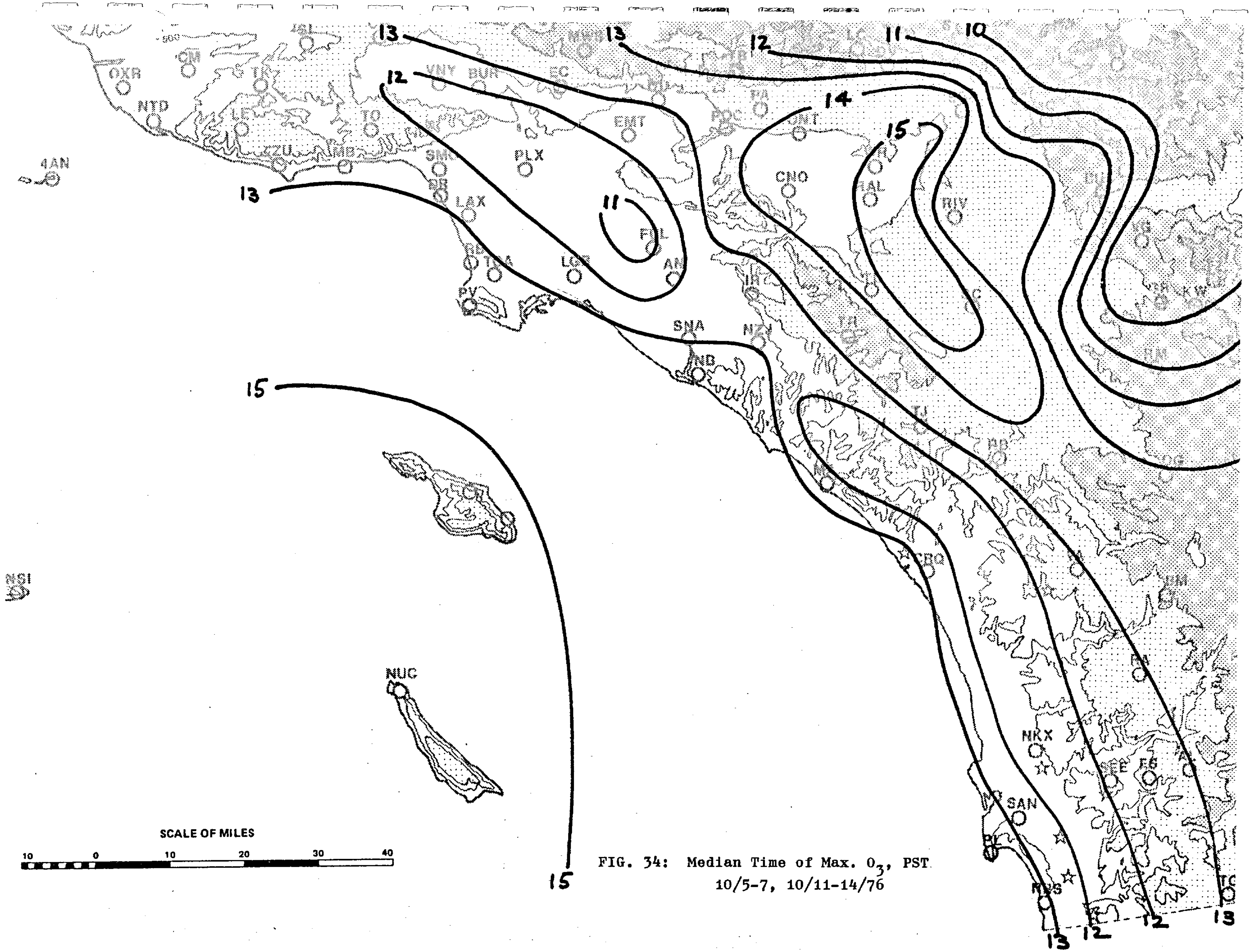

FIG. 34: Median Time of Max. O_3, PST
10/5-7, 10/11-14/76

inland, especially in the South Coast Air Basin, one finds the late occurring maxima associated with inland advection of the photochemical pollution cloud. A similar pattern is found when the "Santa Ana" days were included in the analysis.

The explanation of this variation in timing of the ozone maxima may well lie in the fumigation mechanism, together with the transport of aged photochemical pollution masses out over the off-shore waters and then back on shore with the development of the daily sea breeze.

As the ozone maximum aloft mixes inland, it will be first brought to the surface at inland points, where surface heating is most pronounced. Nearer the coast, the surface heating occurs at a slower rate due to the tendency of low clouds and fog to persist there.

After the ozone mass is brought to the surface, it together with surface-originated ozone, is carried farther inland, and this movement shows up as a late occurrence of ozone maxima at the interior valley points.

Another possible explanation could be as follows: the coastal area contains early morning primary pollutants, which begin to move inland and age to form an ozone maximum, which then grows and is carried into the far inland areas. Meanwhile the air off-shore containing aged material moves back on shore well after the start of the sea breeze, causing a coastal maximum. It tends to be lower than the ozone maxima found inland, so its progress through the sampling network is not detected as a maximum.

The early-occurring ozone maxima located in the San Bernardino mountain-Coachella Valley sections of Southern California are not readily explainable. It is known that on some occasions the aged cloud from the Los Angeles Basin does register at sampling stations in this area during the night-time hours, in keeping with the well-known transport of the coastal air into the interior of the continent. Figure 34, however, representing the median conditions, seems to say that the continuity of ozone transport on the average is broken between the interior valleys of Southern California and the mountain-desert regions.

F. Relationship Between Ozone Aloft and Surface Ozone

The finding that there are ozone maxima aloft over coastal sections of San Diego, just above the top of the surface mixing layer, caused attention to be directed toward determining if there was a relationship between the ozone concentrations as measured aloft and the ozone maxima as recorded at the surface by the air sampling stations operated by San Diego APCD.

Figure 35a,b, presents scatter diagrams of comparisons between the ozone aloft (measured near noon over coastal San Diego County) and at the surface. Coastal stations such as Oceanside, San Diego (downtown), and Chula Vista show good agreement between the two sets of data. However, the inland stations such as El Cajon and Alpine show no such agreement. This indicates that other factors are involved; for example, the inland stations may be recipients of pollution from other than the ozone aloft source.

The "Santa Ana" days of October 8-10, 1976 are specifically indicated on the scatter diagrams, since they represent a non-fumigation situation, the aged photochemical pollution cloud being at the surface as it was transported along. The lack of concurrence of ozone aloft and surface station readings on these days at Oceanside is explainable by the fact that the ozone aloft readings

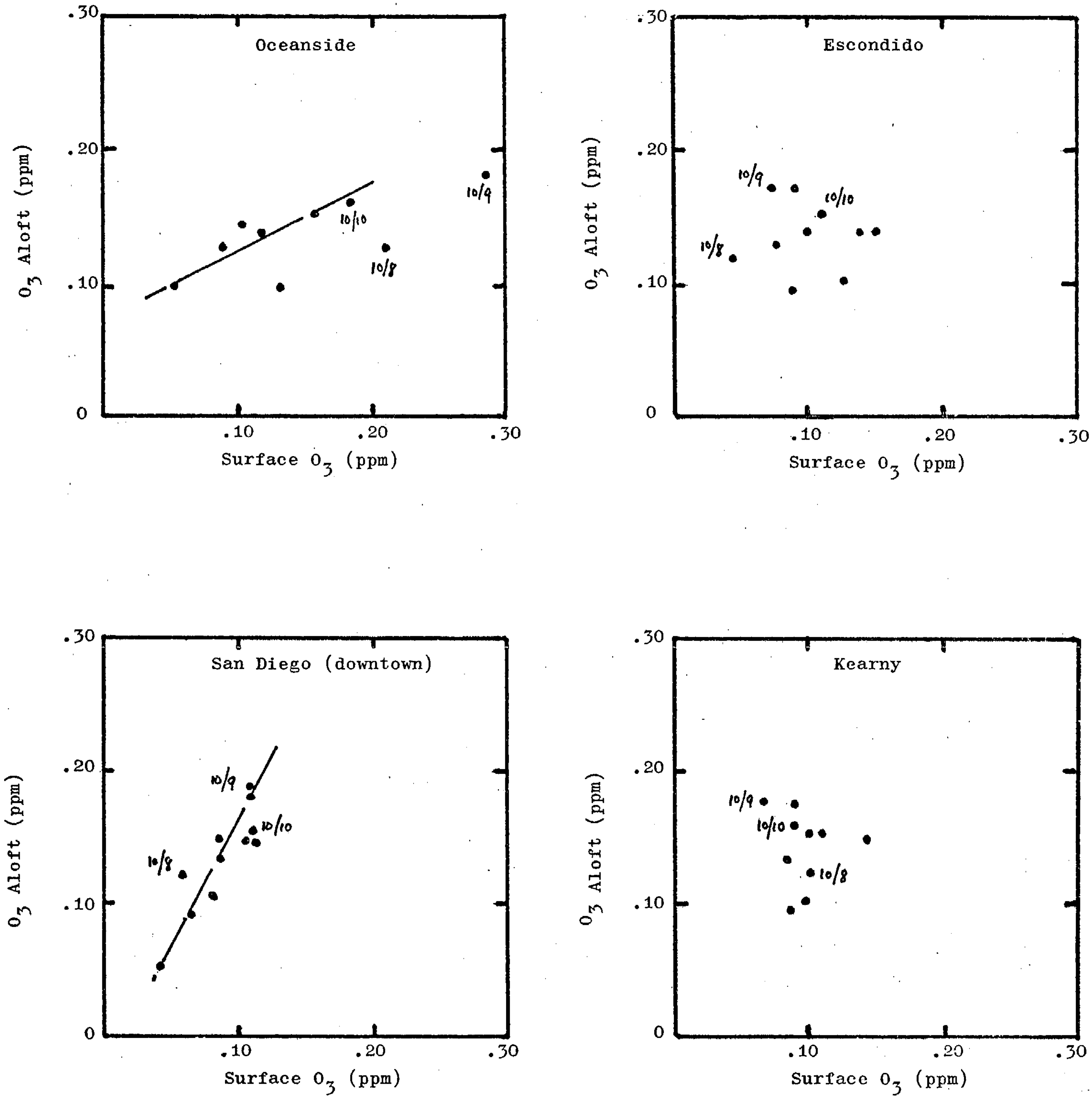

FIG. 35a: Comparison of Max O_3 Aloft, near noon, as measured over Northern Coastal San Diego County, with Max. Hourly O_3, Measured at APCD Sampling Stations.

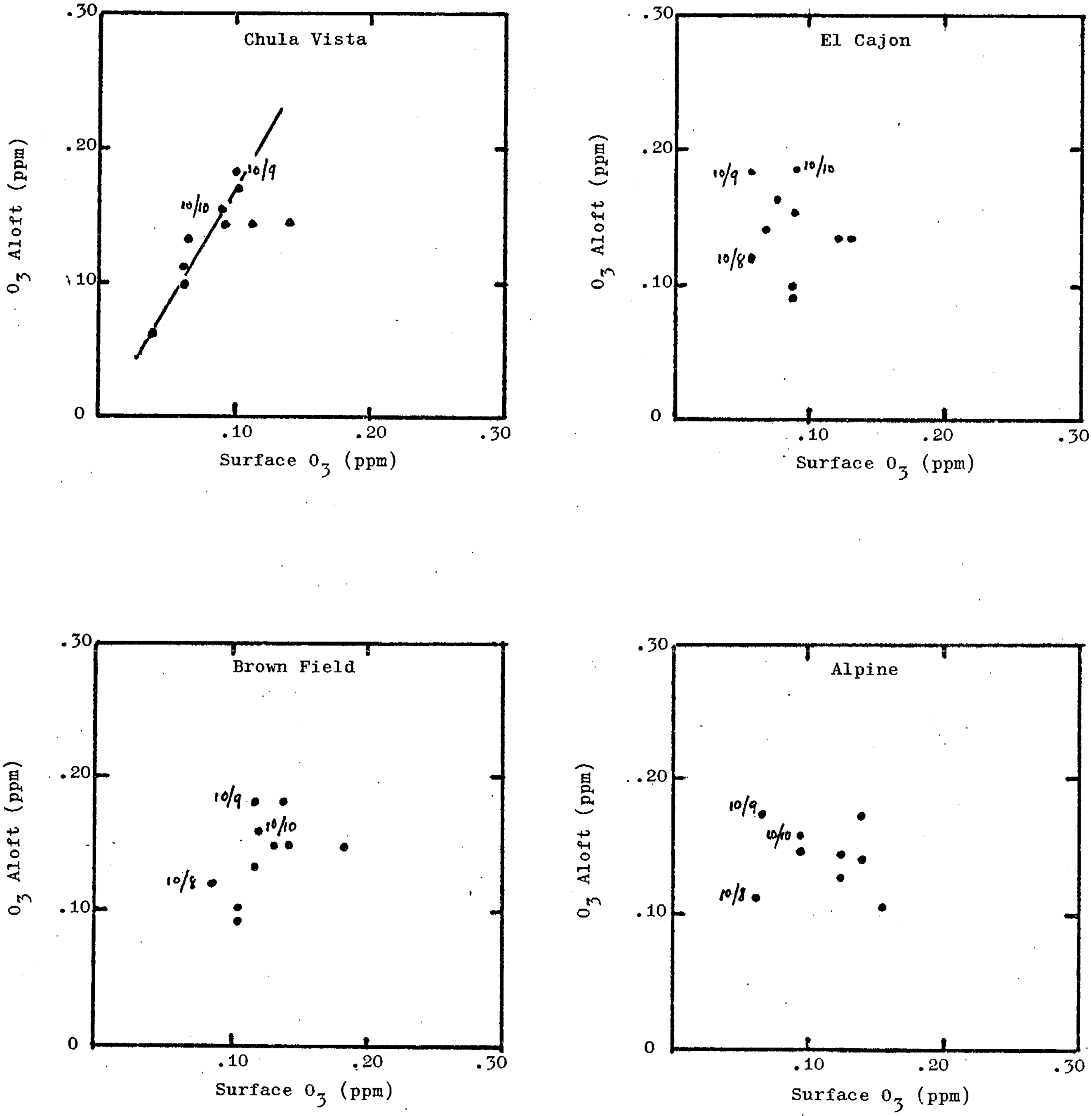

FIG. 35b: Comparison of Max. O_3 Aloft, near noon, as Measured over Northern Coastal San Diego County, with Max. Hourly O_3, Measured at APCD Sampling Stations.

were taken near noon, while the surface ozone maxima occurred late in the afternoon, as the low level north-westerly winds carried the pollution cloud southward.

VIII CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

It was evident from the data that under "Santa Ana" flow conditions the observed high ozone concentrations in San Diego County are due to transport of an aged photochemical pollution cloud from the urban complex occupying the South Coast Air Basin.

In addition, on some days that more nearly represent normal coastal air flow conditions ozone concentrations are transported aloft from the South Coast Air Basin to the San Diego Air Basin.

While good agreement was found between ozone aloft and at the surface at coastal locations in San Diego County, no such correspondence was noted between ozone aloft and surface values at eastern inland stations, indicating that the eastern stations may be recipients of pollution from a source other than the one found aloft.

How these maxima aloft are brought to the surface, to be measured by the surface-based network of air monitoring stations, is still an open question. The possibility exists that a fumigation process occurs, as the daytime surface heating effect results in a deepening mixed layer which finally taps the ozone aloft and returns it to the surface. An alternate possibility involves differential aging of what basically is a uniformly polluted air mass. The air layer aloft, above the coastal cloud deck, receives the full effect of the ultra violet radiation from the sun, so the ozone maximizes early there. The air in and below the clouds does not receive enough radiation until later in the day when the clouds are dissipated. Then this air, undergoing the aging process, finally reaches the same concentration of ozone that the upper level air had achieved earlier.

Looking at all the days studied in this project, only on days when a persistant southerly component wind occurs does it appear that no South Coast Air Basin influence exists in the San Diego area.

In terms of concentrations of ozone occurring under the various flow regimes, the "Santa Ana" situation produced a maximum hourly concentration of 0.29 ppm as measured at a surface station during the course of this study. Those cases associated with transport of ozone aloft from the South Coast Air Basin produced a maximum surface reading of 0.14 ppm at Brown Field, (a value of 0.15 ppm at Alpine occurred on the last day of the field operation. Its trajectory, however, was sufficiently complex so as to make it impossible to say with certainty that its origin was the South Coast Air Basin).

The only day which appeared to present a situation involving just the San Diego source (10/11/76) produced a maximum ozone value of 0.12 ppm at Alpine.

While the program undertaken represented only a small portion of the "smog season" of 1976, it did detect a moderately severe smog attack of the "Santa Ana" variety. It also indicated that transport from the South Coast Air Basin occurs under more normal summer conditions, and thus has an additive effect on ozone pollution levels in San Diego.

B. Recommendations

To establish the frequency of the transport mechanism from the South Coast Air Basin a program of daily winds aloft, temperature and ozone soundings made along the northern San Diego County coast should be instituted during the "smog season". These soundings, made once per day during mid-morning, together with data from ozone monitors at sea level and at elevated points on Catalina and San Clemente islands, would be useful in developing transport patterns affecting

San Diego.

The soundings, too, could be used to predict the timing and magnitude of the highest ozone concentrations to be expected on the basis of the ozone layers aloft, using estimates of the maximum surface temperatures expected to occur over the San Diego area.

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APPENDIX A

Selected Photographs

Fig. A-1: Project air sampling aircraft, Piper Twin Comanche

Fig. A-2: Haze layer against NW end of Catalina Island, looking north, 10/7/76 1740 PDT

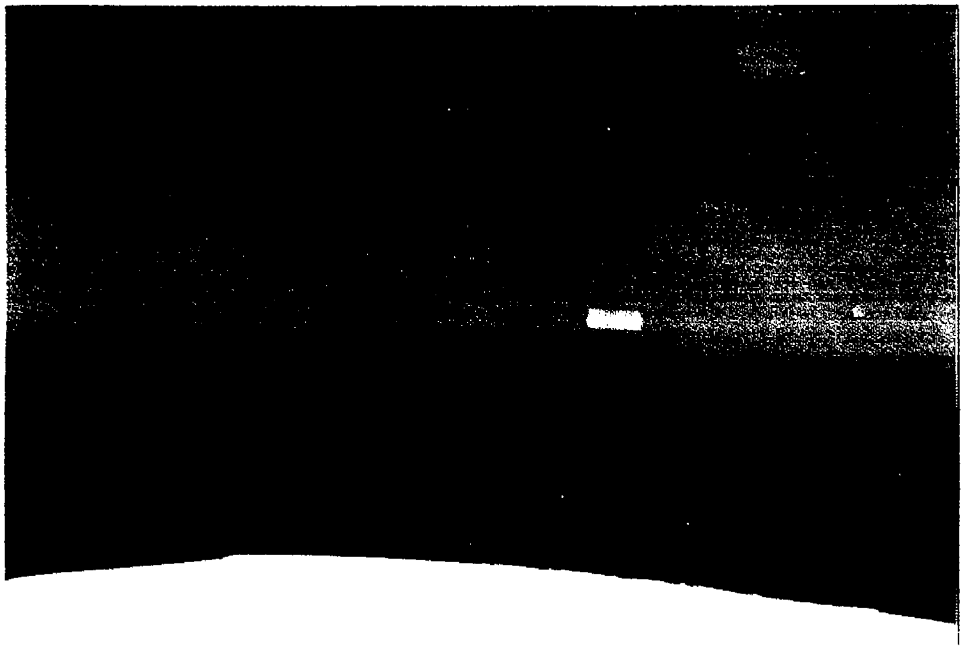

Fig. A-3: Brown smog layer off Catalina Island, taken from aircraft at 200 ft., 10/8/76 1134 PDT.

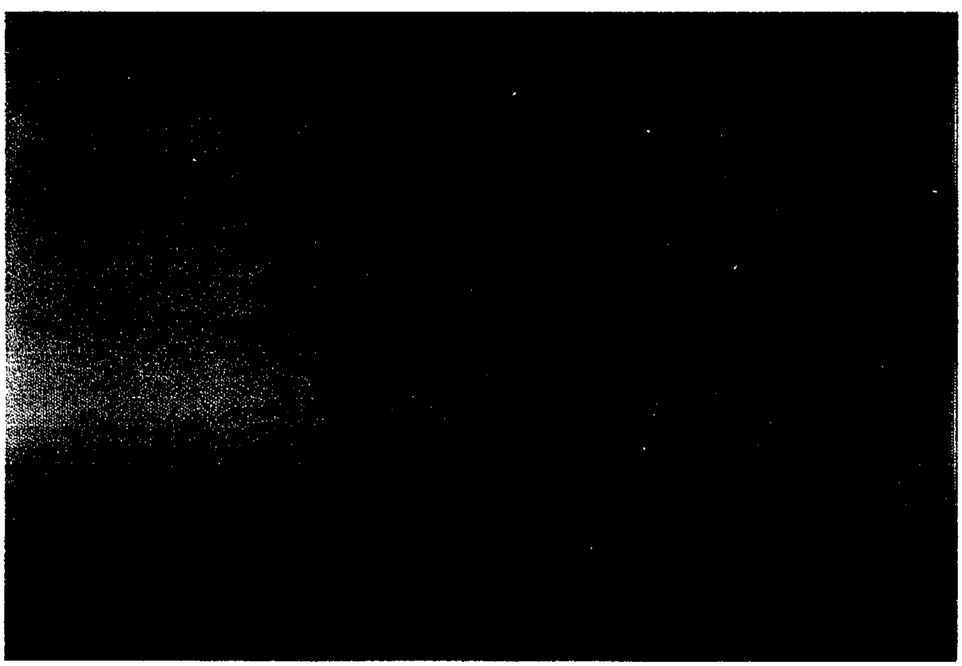

Fig. A-4: Brown smog layer at 1000 ft., Dana Point, 10/6/76 0754 PDT.

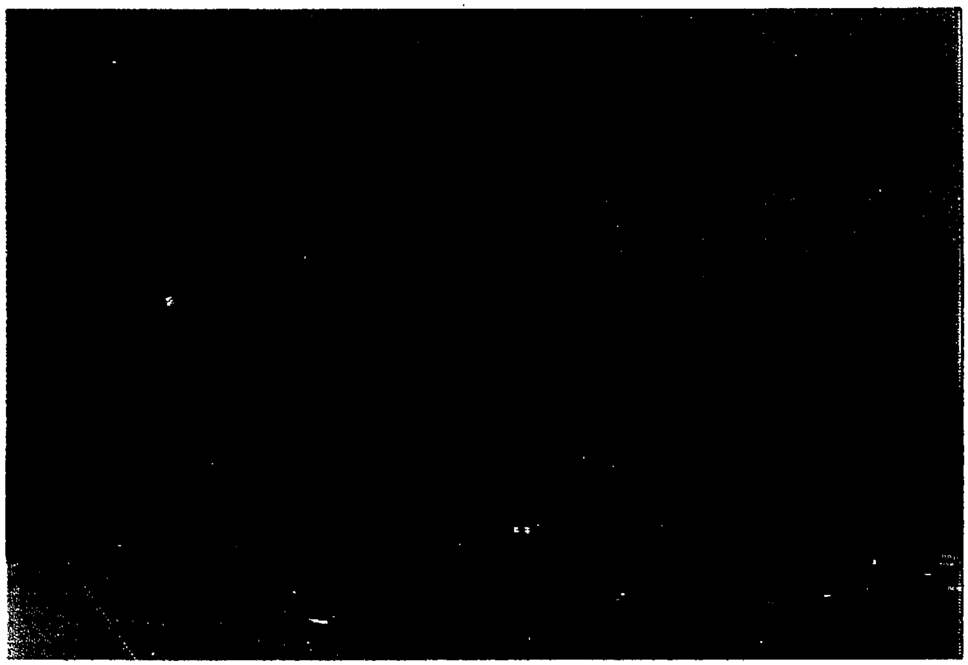

Fig. A-5: Stratus forming from plume of Encina power plant, taken from 1300 ft., 10/6/76, 0802 PDT.

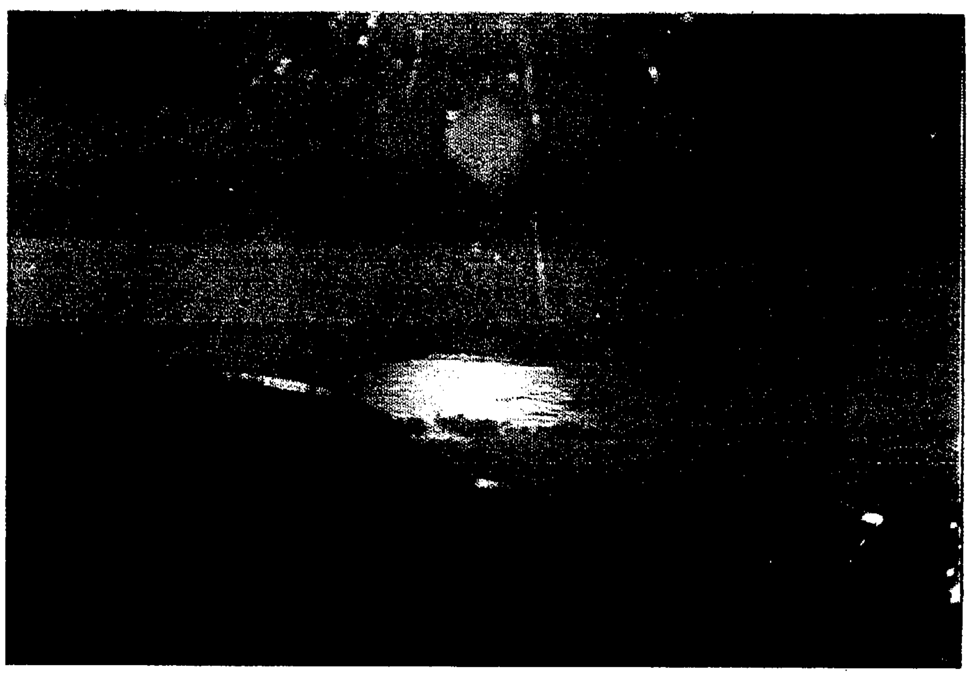

Fig. A-6: Hole in stratus deck, off-shore from Carlsbad, taken from 2000 ft., 10/6/76, 0820 PDT.